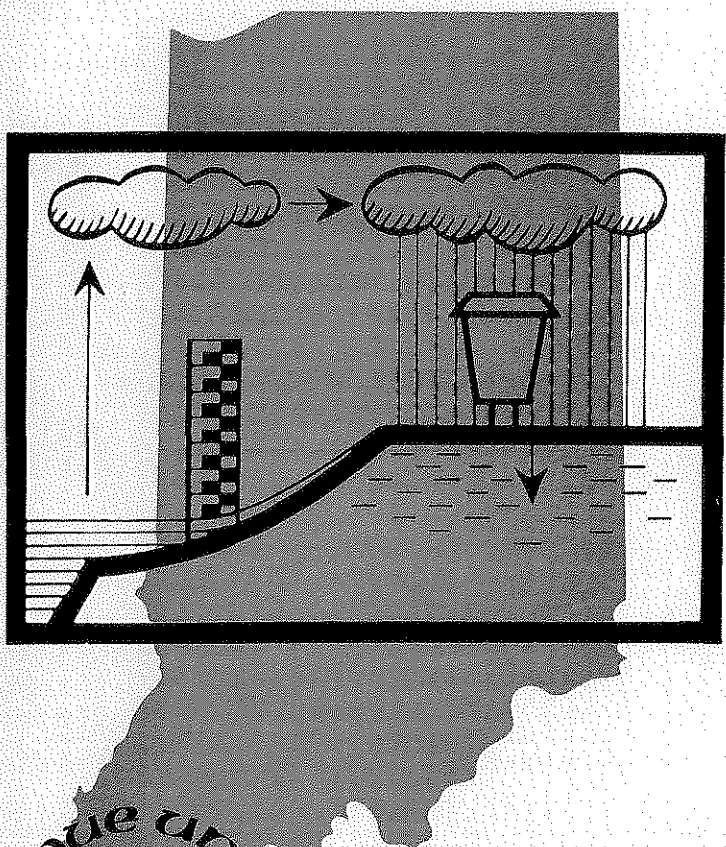
TECHNICAL REPORT NO. 64

SAMPLING AND ANALYSIS OF STORMWATER RUNOFF FROM URBAN AND SEMI-URBAN/RURAL WATERSHEDS

Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities



by

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September 1976

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA

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A completion report for the water quality sub-project of OWRT Project No. C-3277 (Grant No. 14-31-0001-3712) entitled "Systematic Development of Methodologies in Planning Urban Water Resources for Medium-Size Communities".

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INTRODUCTION

In the last ten years it has become a well-known fact that stormwater runoff, particularly from urban areas, can be a substantial source of pollution. While the runoff from a single rainstorm event may not cause a serious threat to streams or lakes, it is the cumulative effect of many such storms which may be harmful. The problem now becomes one of dealing with this type of pollution as a dispersed or "non-point" source.

What can be done to help eliminate, or at least, decrease the effects of stormwater runoff? While data describing runoff quality are readily available, not much is known about the sources of the pollutants or which parameters have the most control over runoff quality. For instance, will increasing the street sweeping interval and/or efficiency cause a substantial decrease in pollutant loadings if a large amount of pollution is still washed off the lawns, houses, and trees? Or could improved land management planning be more effective than increased street sweeping? While these and other questions have not as yet been answered, many advances are being made in the area of runoff abatement and treatment.

The most significant advancement in the area of abatement and treatment has been the use of mathematical modeling techniques to assess stormwater runoff and combined sewer overflow problems. Stormwater models are able to model stormwater quantity and quality.

The cost of abatement or treatment designs for stormwater runoff control can also be computed with stormwater models.

It will be the primary objective of Phase II of this study to analyze the data accumulated to date with respect to model development and verification. However, the main objective of Phase I, reported herein, was to collect and analyze stormwater runoff samples to determine their quality. Samples were obtained from an urban and a semi-urban/rural watershed located in West Lafayette, Indiana. Preliminary sampling was performed in order to develop sampling methodology; i.e., to determine the importance of sampling frequency, duration, etc. on the resultant stormwater pollutographs. It was also the purpose to determine the effects of total rainfall, rainfall intensity, and antecedent dry period on the runoff quality.

This work was carried out in conjunction with the study being done by the Water Resources Research Center of Purdue University for the Title II Project C-3277 entitled "Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities". Funding was provided by the United States Department of Interior, Office of Water Resources Research, under the Water Resources Research Act of 1964 (Public Law 88-379). The Grant No. was 14-31-0001-3713.

REVIEW OF LITERATURE

Introduction

Much work has been done to quantify and qualify stormwater runoff. The quality of stormwater runoff was one of the prime concerns of this study. The literature was surveyed for other data pertaining to the quality of stormwater runoff. Data are presented only for watersheds with separate stormwater sewer systems in order to be consistent with the data obtained during this study. Efforts to evaluate the effects of different parameters on stormwater runoff quality are also presented.

Biochemical and Physical Characteristics of Stormwater Runoff

Two quality parameters used to evaluate the strength of domestic waste are biochemical oxygen demand (BOD) and suspended solids (SS). These same two parameters are commonly used to describe the quality of stormwater runoff.

Burm, et al (1) investigated the quality of stormwater runoff from a watershed in Ann Arbor, Michigan. The watershed had an area of approximately 3800 acres with some rural drainage entering the watershed. The land use was mostly residential and commercial with some light industries. The BOD and suspended solids ranged from 24-49 mg/l and 470-4440 mg/l, respectively. The average of the annual averages were found to be 28 mg/l and 2080 mg/l, respectively.

Runoff from rural cropland in Coshocton and Ripley, Ohio was studied by Weidner, et al (2). Two watersheds in Coshocton contained a wheat crop but different land management techniques were used. The average BOD ranged from 2.9 - 7.2 mg/l for the storms sampled. The average suspended solids were from 500-540 mg/l. The watershed in Ripley was an apple orchard. The average BOD and suspended solids were found to be 8.4 mg/l and 575 mg/l, respectively.

AVCO Economics Systems Corporation (3) collected samples of stormwater runoff from 15 test areas within the Tulsa metropolitan area. The test areas contained a variety of uses, including industrial, commercial, residential, and open areas. The average BOD ranged from 8-18 mg/l, with the overall overage being 11.8 mg/l. The maximum BOD of 39 mg/l occurred in a residential area. The suspended solids had an overall average of 367 mg/l, with a range of 84-2052 mg/l.

A 264 acre watershed with separate stormwater sewers in Washington, D.C. was monitored during a study by Roy F. Weston, Inc. (4). The quality of the dry-weather flow was determined to average 18 mg/l for BOD and 68 mg/l for suspended solids. The BOD of the stormwater runoff was 3-90 mg/l with an average of 19 mg/l. The suspended solids ranged from 130-11,280 mg/l, with the average being 1697 mg/l.

The Envirogenics Company (5) studied stormwater runoff quality from watersheds with separate stormwater sewers in Sacramento, California. The BOD and suspended solids ranged from 24-260 mg/l and 19-211 mg/l, respectively.

Angino, et al (6) studied the runoff quality from the Naismith Ditch drainage basin in Lawrence, Kansas. Naismith Ditch is a residential area of about 460 acres. The BOD was determined for only one storm and averaged 11.4 mg/l. Suspended solids averaged 235 mg/l for the 22 samples taken. The range of suspended solids was 78-545 mg/l.

Even though the study of Sartor and Boyd (7) concentrated on the quantity and characteristics of materials found in city streets, a general conclusion was reached in regard to the strength of stormwater runoff resulting from these streets. They calculated the amount of pollutants which could possibly be washed into the receiving stream in a typical U.S. city. This calculation was based on the first hour of a moderate-to-heavy storm (brief peak to at least ½ in/hr) and a street sweeping interval of five days. Based on a population of 100,000 and a total land use of 14,000 acres (75 % residential; 5 % commercial; and 20 % industrial) having 400 curb miles, the following street runoff was estimated following a 1-hour storm: Settleable + Suspended Solids = 570,000 lbs/hr.; BOD = 5,600 lbs/hr.; and COD = 13,000 lbs/hr.

Hergert (8) studied several watersheds in Lincoln, Nebraska. Two of the watersheds were completely developed residential area. The BOD and suspended solids ranged from 8-885 mg/l and 245-2020 mg/l, respectively. The other watershed was a new housing development with considerable construction being done at the time. The BOD and suspended solids for this watershed ranged from 6-60 mg/l and 18-26,750 mg/l, respectively. The extremely high suspended solids resulted from excessive scour of construction sites during runoff.

Four watersheds with separate stormwater sewers in Des Moines, Iowa were studied by Davis and Borchardt (9). The watersheds were predominately residential. Only one contained any industrial usage and it was only 5 %. The range of average BOD for each watershed was 44-63 mg/1, with an overall average of 53 mg/1. The average suspended solids ranged from 315-578 mg/1, with the overall average being 448 mg/1.

Whipple, et al (10) determined the runoff pollution to the Whippany River from the vicinity of Morristown, New Jersey, a non-industrial area. They determined what part urban runoff pollution played in the overall water quality of the Whippany River by modeling the river. The river was sampled upstream and downstream of the city. The identified waste effluents were also determined. Then by differences in the before-mentioned water qualities, the unrecorded pollution was determined. During rainfall the unrecorded pollution was assumed to be almost entirely from the stormwater runoff. The BOD and suspended solids ranged from 2.9 - 10.8 mg/1 and 74-150 mg/1, respectively. The study concluded that 0.02-0.03 lbs BOD/person/day can be produced by urban runoff from urban residential and shopping areas.

Whipple, et al (10) also listed runoff data for rural areas. Rural areas were defined as areas with woods, pasture land, crops on level land, and single-family housing. The concentration of BOD for these areas averaged less than 2 mg/1 during dry weather and 3.0 mg/1 during wet weather.

Beers (11) evaluated the quality of rainfall and stormwater runoff from an individual home located in an eastern suburb of Cincinnati, Ohio. Runoff quality was obtained for roof, driveway, and lawn surfaces. BODs ranged from approximately 2.5 to 30 mg/l, while suspended solids ranged from approximately 3 to 440 mg/l.

Three different land-use watersheds in West Lafayette, Indiana were sampled by Schulz (12). The watersheds consisted of an urban, semi-urban, and rural area. BODs ranged from 2.5 - 145 mg/l; 4 - 20 mg/l; and 2-7 mg/l for each of the three watersheds, respectively. Similarly, suspended solids ranged from 20-825 mg/l; 85-2700 mg/l; and 17-650 mg/l, respectively.

McElroy (13) sampled an urban and a semi-urban/rural watershed in West Lafayette, Indiana. The urban watershed was a 29-acre residential area. The semi-urban/rural watershed contained 292 acres and consisted of cropland and a housing sub-division. The peak BOD and suspended solids for the urban watershed ranged from 11.0 - 44.5 mg/l and 62 - 250 mg/l, respectively. The same two parameters ranged from 3.0 - 7.0 mg/l and 6 - 170 mg/l, respectively, at the semi-urban/rural watershed.

Dornbush, et al (14) refer to a study which was done on the runoff quality from several small areas of farmland. The type of cover and cultivation practices heavily influenced the suspended solids present in the runoff. The suspended solids concentration varied from 6 - 15,200 mg/l. The BOD found in the same runoff ranged from 7 - 17 mg/l.

An agricultural watershed in southwestern Iowa was sampled for runoff quality by Burwell, et al (15). The watershed consisted of 95 % cropland and 5 % pasture and feed-lots. The suspended solids ranged from 0 - 2000 mg/l. No BOD data were available.

Kluesener and Lee (16) monitored the stormwater runoff quality from a residential area with separate storm sewers in Madison, Wisconsin. No BOD data were taken but the suspended solids averaged 280 mg/l.

Thompson, et al (17) monitored stormwater runoff from a 1499-acre watershed in Lubbock, Texas. The land uses included were residential, commercial, and industrial. The range of average CODs was 110 - 461 mg/l, with an overall average of 215 mg/l. The BOD/COD ratio was determined to be 0.105. The suspended solids ranged from 144 - 670 mg/l, with an overall average of 296 mg/l.

The study by Colston (18) sampled stormwater runoff from the Third Fork Creek Basin in Durham, North Carolina. The basin contained six sub-basins and most of the runoff was carried by natural drainage ditches. The sub-basins consisted of varying degrees of different land uses, although two sub-basins were predominately residential.

The average base flow concentrations for BOD and suspended solids were 15 mg/l and 50 mg/l, respectively. The range of BOD concentration during storms was 2 - 182 mg/l. The average BOD was 60 mg/l. The average suspended solids was 1223 mg/l, with a range of 27 - 7340 mg/l.

Colston noted that he experienced considerable difficulty with results from the standard BOD test. His results showed that as the sample in the BOD bottle was decreased, the BOD exertion would increase. Several reasons given for this phenomenon were: 1) the inhibiting effect of certain heavy metals; 2) the presence of an unidentified inhibitory compound; and/or 3) inherent difficulties with the standard BOD test. He states that the BODs presented are not to be considered valid but rather as an indication of the magnitude of the problem with urban runoff BOD.

Bacteriological Characteristics of Stormwater Runoff

Total and fecal coliform analyses have also been used to characterize the quality of stormwater runoff. Geldreich (19) considered the significance of fecal coliforms and concluded that the fecal coliform test has been demonstrated to be the most accurate measurement of the occurrence of warm-blooded feces in polluted water. It is for this reason that the presence of total and fecal coliforms in stormwater runoff is usually determined.

Geldreich (19) found that fecal contamination in separate stormwater systems is ultimately related to the fecal discharges of cats, dogs, and rodents in the urban areas. Agricultural land drainage contains the fecal contamination from farm animals and wildlife. He showed that cat and dog feces contain 7,900,000 and 23,000,000 organisms per gram, respectively, and that rat, chipmunk, and rabbit feces contain 330,000 organisms per gram, 150,000 organisms per gram, and 20 organisms per gram, respectively.

Weibel, et al (20,21,22) investigated the bacteriological quality of stormwater runoff from a 27-acre residential, light-commercial suburb of Cincinnati, Ohio. The total coliform counts exceeded 2,900 organisms per 100 ml, 58,000 organisms per 100 ml, and 460,000 organisms per 100 ml in 90 percent, 50 percent, and 10 percent of the samples, respectively. The fecal coliform counts exceeded 500 organisms per 100 ml, 10,900 organisms per 100 ml, and 76,000 organisms per 100 ml in 90, 50, and 10 percent of the samples, respectively.

In a more recent study of the same Cincinnati suburban watershed performed by Evans, et al (23), the following ranges of coliform densities were found: Total coliforms, 23,900 - 45,000,000 organisms per 100 ml; and, fecal coliforms, 1,050 - 1,210,000 organisms per 100 ml.

Palmer (24) studied stormwater runoff from a watershed in Detroit resulting from four separate low-intensity storms in 1960. The range of total coliforms (expressed in organisms per 100 ml) for the four storms were 2,300 to 430,000. Palmer (25) had previously determined a range for total coliforms of 25,000 to 930,000 organisms per 100 ml for the same watersheds.

Burm and Vaughan (26) examined total and fecal coliform densities in stormwater runoff from an Ann Arbor watershed. The maximum total and fecal counts were 49,000,000 and 4,300,000 organisms per 100 ml, respectively.

Benzie and Courchaine (27) determined median total and fecal coliform densities for the same watershed in Ann Arbor and found them to be 1,200,000 and 82,000 organisms per 100 ml, respectively.

Geldreich, et al (28) compared total and fecal coliform densities of stormwater from different areas in Cincinnati and compared the effect of climatic seasonal changes of the densities. The ranges of the median values for total and fecal coliform densities were 260 - 290,000 and 20 - 47,000 organisms per 100 ml, respectively.

In the study performed by the AVCO Corporation (3) in Tulsa, the total and fecal coliform densities ranged from 5,000 to 400,000 and from 10 to 18,000 organisms per 100 ml, respectively. In a study by the Envirogenics Company (5) in Sacramento, fecal coliforms ranged from 2,400 to 1,000,000 organisms per 100 ml.

The Public Health Service (29) found that in Oakland, California total coliform densities of stormwater runoff varied from 2,300 to 2,400,000 organisms per 100 ml with a mean value of 293,000 organisms per 100 ml. Bryan (30) examined the bacteriological quality of stormwater runoff in Durham, North Carolina and reported that for 37 samples the densities of fecal coliforms ranged from 3,000 to 1,900,000 organisms per 100 ml. The Los Angeles Flood Control District (31,32) determined the ranges of total coliforms to be 0 to 1,100,000 organisms per 100 ml.

Weidner, et al (2) examined total and fecal coliform quality of stormwater runoff in Ohio and found the median densities to range from 2500 to 8100 organisms per 100 ml and less than 2 to 1200 organisms per 100 ml for total and fecal coliforms, respectively.

Other studies have been performed in Toronto, Canada, Welland, Canada, Stockholm, Sweden, Pretoria, South Africa, and Seattle, Washington (33).

Effects of First Flush, Rainfall Intensity, and Antecedent Dry Periods on Stormwater Runoff

Several investigators have tried to relate stormwater runoff quality to parameters such as "first flush", rainfall intensity, and antecedent dry period. Such parameters may be useful in explaining why some runoff is of worse quality than some other runoff.

Buckingham (4) states that a "first flush" effect was evident during all storms sampled for a watershed in Washington, D.C. He illustrates the dramatic effect that the "first flush" of an earlier storm had on a storm which occurred only three hours later. The first storm had a peak BOD and suspended solids of 17 mg/l and 11,200 mg/l, respectively. However, the peak BOD and suspended solids in the second storm were only 7 mg/l and 1740 mg/l, respectively.

Herbert (8) found that a "flush" effect at the start of runoff was common for most storms sampled. However, some concern was expressed about "first flush" effects during some storms. The concern resulted from a double peak in the concentration curve. The investigator felt that the initial peak may have resulted from stagnant water found in the drainage channels during dry weather and that the second peak may have actually constituted the "first flush".

Herbert also concluded, based on his limited data, that the season and antecedent dry period may have little effect on stormwater quality. He also concluded that a general straight-line relationship existed between pollutional loading (lb/acre/storm) and total rainfall (inches) when the data was plotted on a semi-log plot. Pollutional loading was placed on the logarithmic scale.

Data collected in Des Moines, Iowa (9) tended to support the "first flush" theory. It was also observed that BOD and suspended solids concentrations generally decreased with time and showed little or no relation to flow.

McElroy (13) sampled at both an urban and semi-urban/rural watershed. He concluded that a "first flush" was generally evident for both BOD and suspended solids. A "first flush" of suspended solids, although not very pronounced, was evident at the semi-urban/rural watershed. However, a "first flush" of BOD was not observed.

Kluesener and Lee (16) observed that the suspended solids were the highest during the "first flush" of the basin. They also concluded that higher rainfall intensities swept more solids from the streets early in the runoff event.

Thompson, et al (17) show that the concentration of pollutants was generally the highest during the first samples taken during a runoff event. They concluded that there was no apparent trends for higher intensity thunderstorms to be of poorer quality than that of low intensity, long duration rains.

Regression analysis performed during a study by Colston (18) indicated that the time from the last storm was not a significant indicator of runoff quality.

Vilaret and Pyne (34) performed a study of stormwater quality in Atlanta, Georgia. They found that the time distribution of rainfall for a typical storm of given frequency and duration has little effect on the pollution load washed from a given watershed.

A study done in Bucyrus, Ohio (35) indicated that a linear relationship exists between rainfall per storm and pollutional load discharge (lbs/100 acres) when plotted as an arithmetic plot. This relationship held true for both BOD and suspended solids; however, it was based on data obtained from combined sewers.

DESCRIPTION OF WATERSHEDS AND SAMPLING STATIONS

Introduction

The watersheds and sampling stations used in this study were established for prior studies. The urban watershed is known as the Ross Ade upper watershed and the semi-urban/rural watershed is referred to as the Purdue Swine Farm watershed. The Ross Ade upper watershed was established in a study entitled "Hydrologic Study of an Urban Watershed in West Lafayette, Indiana"(36). The Purdue Swine Farm watershed was initiated for a study entitled "Effects of Urbanization on Runoff from Small Watersheds"(37).

The boundaries of the watersheds and location of the gaging-sampling stations used in this study are shown in Figure 1. The Civil Engineering Building is shown in order to illustrate its proximity to the watersheds.

Urban Watershed

The Ross Ade upper watershed is located in West Lafayette, Indiana. The Ross Ade upper watershed is a fully developed residential area located northeast of Northwestern Avenue, West Lafayette. Its location is generally north and approximately ½ mile from the

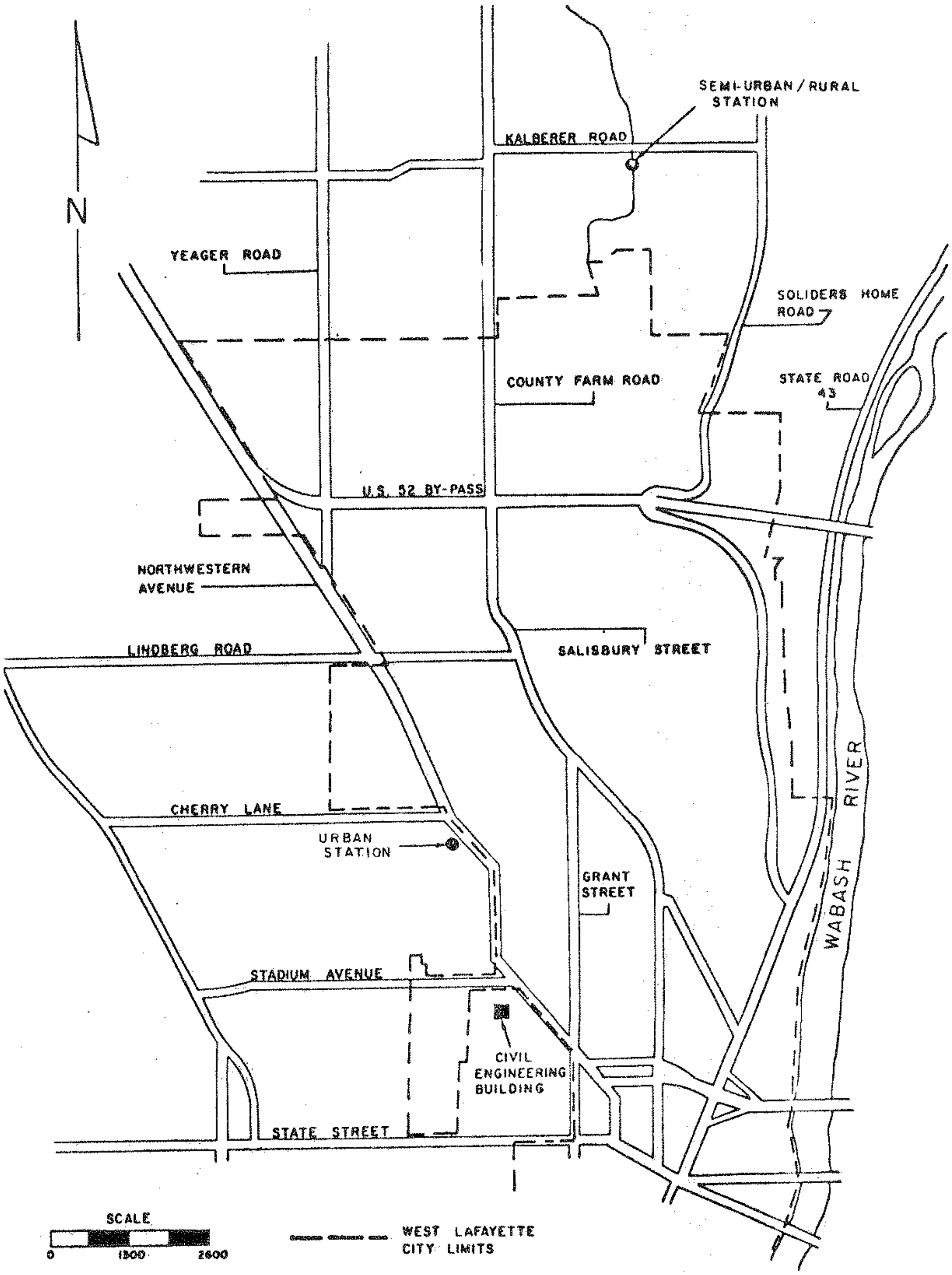

FIGURE 1– LOCATION OF SAMPLING STATIONS AND THE CIVIL ENGINEERING BUILDING

Civil Engineering Building.

The Ross Ade upper watershed consists of 29 acres and contains 72 single-family dwellings. The terrain is hilly and the lots are all grass covered. The population, based on 3.5 persons per dwelling (38), is approximately 252 persons or a population density of 8.7 persons per acre. Eleven of the 29 acres, or about 38 percent, are impervious. Roof tops account for approximately five acres of the impervious area while the remaining six acres consist of paved areas, such as streets and driveways (37). Figure 2 shows the watershed boundary, drainage system, and location of gaging-sampling station.

The gaging-sampling station is located in the northeast corner of the Purdue campus just west of Northwestern Avenue. The U.S. Geological Survey established this gaging station in 1964. A ground level picture is shown in Figure 3. The gaging station is a concrete pit about 15 feet deep. A trap door, at ground level, and a ladder provide access to the floor of the pit. The storm sewer empties into a 6-foot deep by 6-foot wide concrete flume which runs underneath the gaging station. A trap door in the floor of the pit and another ladder provide access to the flume. All urban runoff samples were taken from this flume.

A Columbus-type deep notch weir with a crest length of six feet is located at the downstream end of the flume to measure the stage. A stilling well, located to one side of the instrument pit, is connected to the flume six feet upstream of the weir. A float in

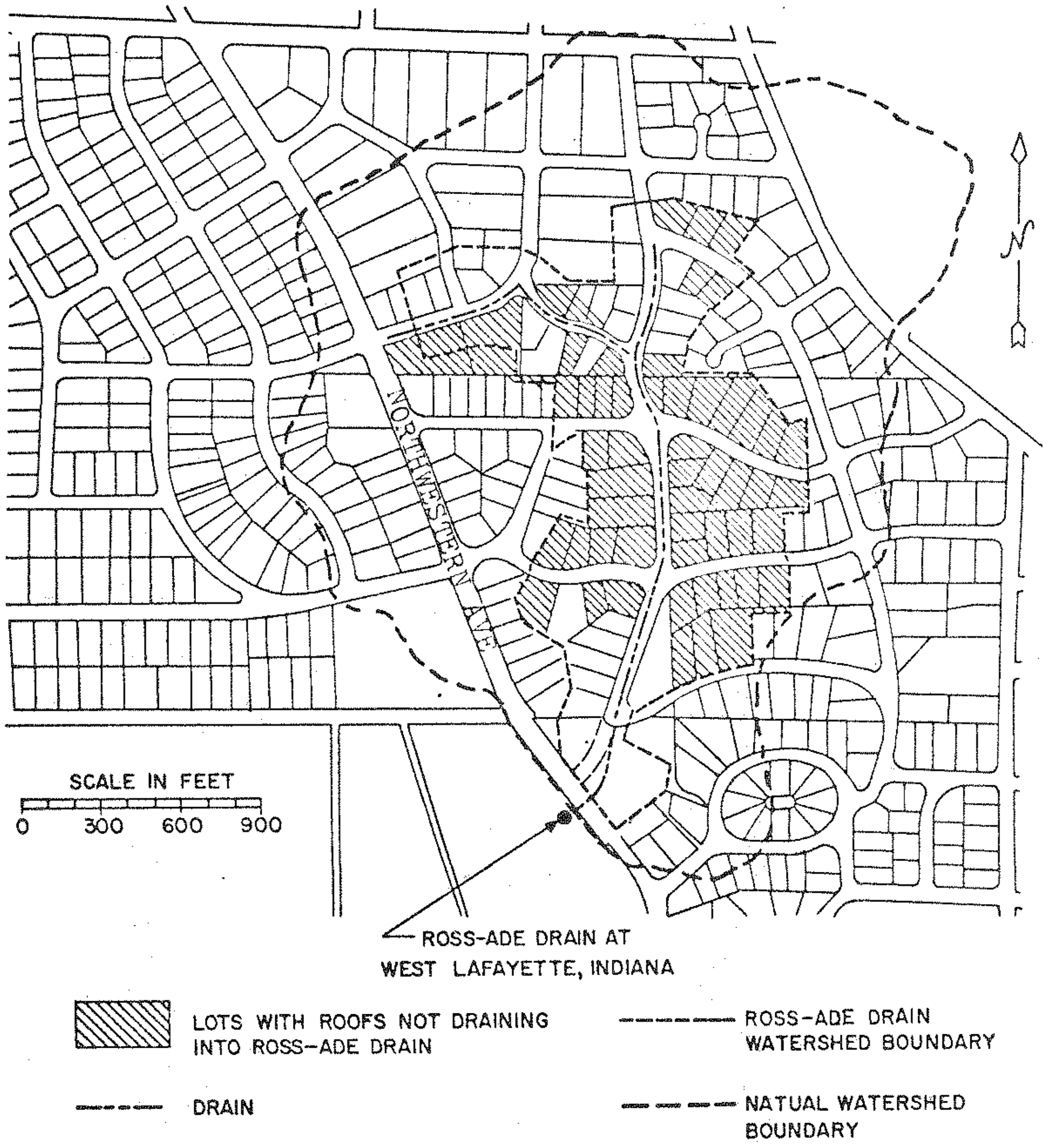

Figure 2. Ross Ade Upper Watershed (37).

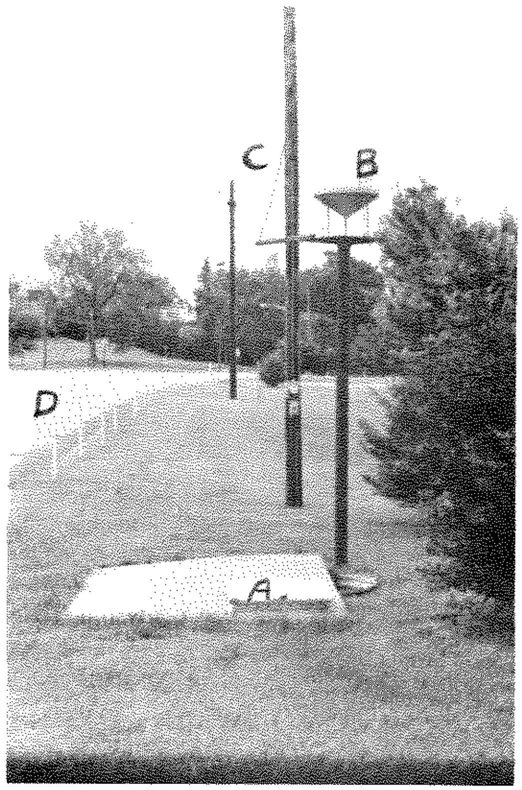

Figure 3 - Urban Watershed Gaging-Sampling Station.

A. Entrance to gaging-sampling station

B. Rainfall receiver

C. Temperature sensor

D. Northwestern Avenue

the stilling well is connected to a Leupold-Stevens A-35 continuous stage recorder through a pulley arrangement.

The Leupold-Stevens A-35 continuous stage recorder is also used to record cumulative rainfall and air temperature. The recorder has a 20-inch chart and is driven at a rate of 144 inches per day so that readings can easily be made for 1 minute intervals. The rain gage, which has a 16-inch diameter rainfall receiver, and a temperature sensor, is located 8 feet above ground level (Figure 3).

The runoff sampling equipment, which consists of a floatless liquid level control, power supply, and an automatic sequential composite sampler, is also housed in the gaging station. The sampler is placed on the floor of the pit which is about 8 feet above the liquid level in the sewer. The sample is collected from the sewer through "Tygon" tubing and distributed in the polyethylene gallon containers placed under the sampler. Complete details of the sampling equipment are included in a leter section.

Semi-Urban/Rural Watershed

The semi-urban/rural watershed is located about two miles north of the Purdue University campus (Figure 1). The terrain of the watershed, which extends in a south-north direction, is flat with a gentle slope in the northern direction. The watershed has an area of 292 acres and consists of a residential area, with some development to be completed, and farm land. The residential area is composed of 178 acres with the remaining 114 acres as farm land. The population of the watershed is approximately 1,000 persons with almost all of this number being from the residential area. This gives a population density of 3.4 persons per acre.

The gaging-sampling station is located at the northern edge of the watershed. The station is about 3 miles north of the Purdue University campus and is located 150 feet upstream of the culvert at Kalberer Road. The watershed boundary, drainage system, and gaging-sampling station locations are shown in Figure 4.

The station utilized two Parshall flumes for flow measurement during two earlier studies (12, 13). However, backwater effects, caused by a new culvert design at Kalberer Road, necessitated discontinuing the use of the Parshall flumes for flow measurement. The larger steel Parshall flume with a throat width of 8 feet was left in place while the smaller flume was removed. The upstream end of the Parshall flume was closed off with a steel plate which consisted of a rectangular weir over a triangular weir as shown in Figure 5. Such an arrangement allows accurate calibration of both small and large flows.

All of the instrumentation is in a precast concrete shelter, which is 5-foot by 10-foot by 7-foot deep, and located approximately 30 feet from the centerline of the drainage ditch. The top of the shelter is about six inches above ground level and access is provided by a trap door and a ladder.

A Stevens Duplex 2A-35, 20-inch chart stage recorder is used to record stage, rainfall, and temperature. Two 12-inch diameter steel

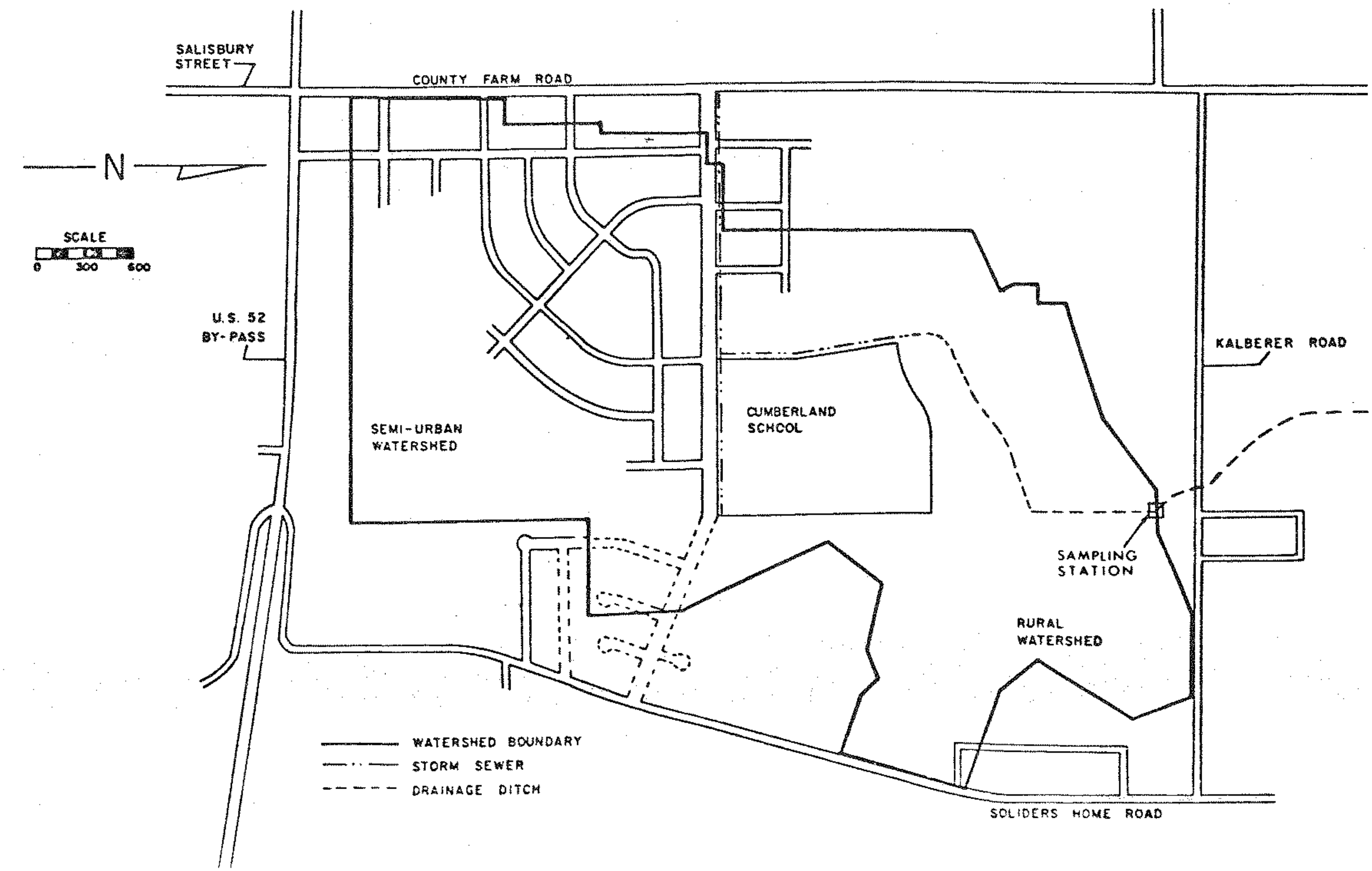

Figure 4 - Combined Semi-Urban/Rural Watershed and Sampling Station(13).

Figure 5 - Weir Plate Installed on Parshall Flume Looking Downstream toward Culvert at Kalberer Road.

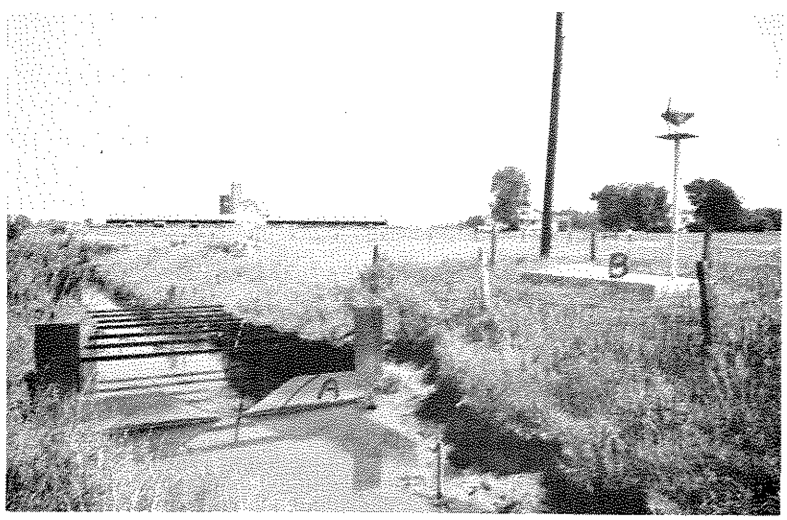

Figure 6 - Semi-Urban/Rural Gaging-Sampling Station Adjacent to Drainage Ditch.

A. Sample collection tubing

B. Entrance to gaging-sampling station

cylinders serve as stilling wells. One is connected into the drainage ditch upstream of the weir and the other just downstream. A float in each stilling well is connected to the recorder through a pulley system and thus allows continuous stage monitoring. The rain gage uses a 22.624-inch diameter rainfall receiver. The receiver and a temperature sensor are mounted eight feet above ground level as shown in Figure 6.

The sampling equipment is also located in this shelter. The sampling equipment is the same as that used at the urban sampling station. However, another stilling well, 3-inch by 4-inch by 6-foot deep, was constructed using ½-inch polyethylene. This stilling well is connected with a galvanized tee to the plumbing which serves the existing stilling wells used to measure the flow. Soft copper tubing, 3/8-inch inside diameter, was run from just upstream of the weir in the drainage ditch into the shelter and connected to the sampler. A detailed description of the sampling equipment is given in the next section.

Description of the Sampling Equipment

The sampling equipment used in this study was purchased for an earlier study (12). The sampling equipment at each station consisted of a Sentry Sequential Composite Sampler, a Charles F. Warrick Floatless Liquid Level Control, a Sears Model 28-7108 3-amp

12-volt battery charger, and an isolation transformer. The Sentry Automatic Sequential Composite Samplers were purchased from the N-Con Systems Company, Larchmont, New York. Figure 7 presents the sampling equipment. A description of the components of the samplers is given in Figure 8.

The Sentry Sampler has a peristaltic (squeeze tube) pump which can be operated as a positive displacement or a purge-type pump. The pump operation is controlled by a microswitch for each mode of operation. The microswitches are activated by "keys" which are placed on a timing drum. The timing drum is connected to a timer which makes one revolution every hour.

The Sentry Sampler is capable of obtaining a variety of sample volumes composed of a variable number of aliquots. The variation in sample size and number of aliquots is possible because of the keys used to program the timing drum. Besides the before-mentioned purge and pump keys, another type of key initiates a switch which controls the distribution arm. In addition, the sampler has a control knob to set the time for pumping and purging from about 15 seconds up to 4 minutes. Samples used in this study were taken every half-hour and consisted of six 4-minute aliquots. Other sampling intervals were used during preliminary stages of this study.

The operation of the sampler starts by connecting the inlet side of the pump to the stream or sewer to be sampled. The operator must then program the timing drum for the number of samples to be collected each hour and the number of aliquots to make up each sample. The

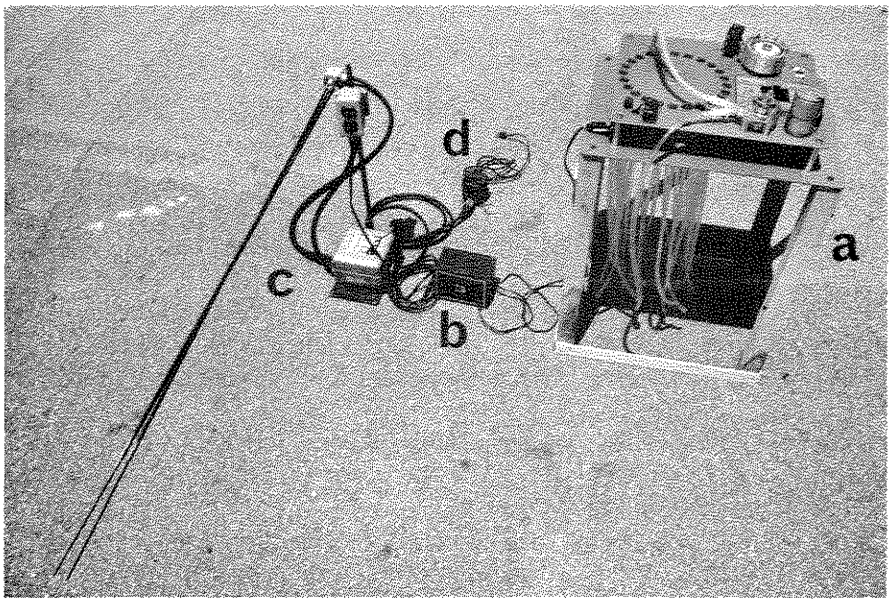

Figure 7 - Typical Sampling Equipment Set-Up.

a. Sentry Sequential Composite Sampler

b. AC/DC converter

c. Warrick Floatless Liquid Level Control with brass electrodes

d. Isolation transformer

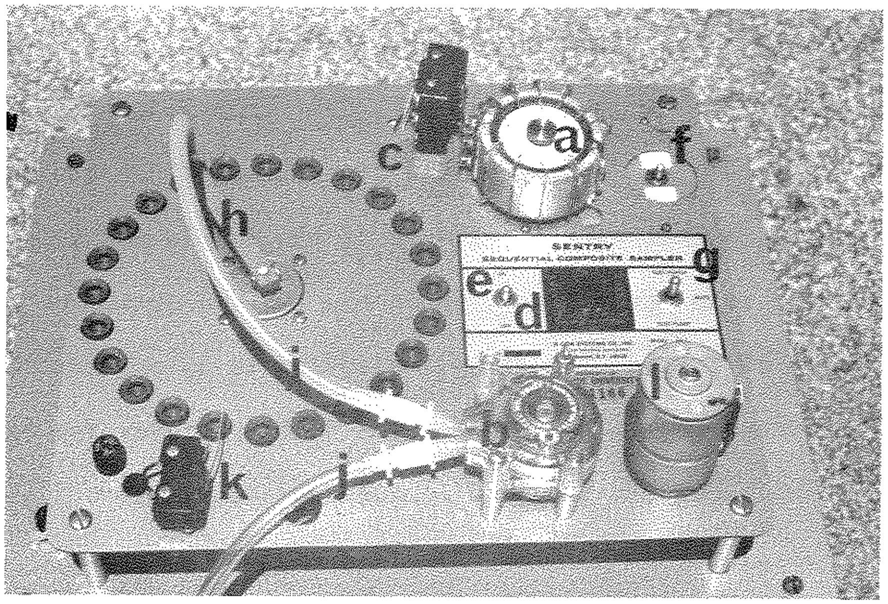

Figure 8 - Sentry Sequential Composite Sampler.

a. Timer with drum and "keys" in place

b. Peristaltic pump

c. Pump/purge/sample index mode microswitches

d. Knob for setting pumping time

e. Main control switch

f. Selector switch for continuous or 24-hour sampling time

g. Selector switch for test pump/automatic/ test purge

h. Sample index distribution arm

i. Discharge tubing to sample containers

j. Suction tubing from sewer or ditch

k. Distribution arm limit switch (system shut-off)

l. Pump motor

operation then becomes automatic. Each aliquot is collected and discharged to its proper sample container. After each aliquot is collected, the inlet line may be purged if desired. Then the pump will reverse and collect another aliquot if the sample is to be composed of more than one aliquot. When the desired number of aliquots have been collected, the distribution arm is automatically indexed to the next sample container. The Sentry Sampler has facilities for 24 sample containers and will automatically shut off after obtaining 24 samples.

The Sentry Sampler operates with a 12-volt DC power supply. The power supply can be dry batteries, a storage battery, or an AC/DC converter. The Sears Model 28-7108 3-amp, 12-volt battery charger was used in this study to supply the necessary power since 110-volt AC power was available at each sampling station.

The Charles F. Warrick Floatless Liquid Level Control insured that sampling was initiated at the beginning of each runoff event. The level control consisted of a switch box, receptacle box, electrode fitting, and two brass electrodes. The electrodes were placed in the stilling well at each sampling station. When the water level rose in the sewer or drainage ditch, the water level also rose in the stilling well. When the water level reached the electrodes, the electrical circuit was completed and the sampling program was initiated for that event.

Due to a severe moisture problem in both instrumentation shelters, the electrical equipment was insulated to protect the people who needed to work in the shelters. For additional protection, an isolation transformer, purchased from the Stancor Company, was included in the electrical circuit at each shelter. The isolation transformer furnished a 110-volt AC power supply free of reference to earth-ground and thus reduced the possibility of accidental shocks.

Installation and Operation of Urban Watershed Sampling Equipment

The sampling equipment for the urban watershed is in the concrete shelter just off of Northwestern Avenue, West Lafayette. The sampler is supported on four 2-foot wooden legs which stand on the floor to allow room underneath for the sample containers. The samples are collected in one-gallon polyethylene containers. Only 12 containers are in place during a sampling event because of limited space in the concrete shelter. A 12-foot length of "Tygon" tubing is connected to the inlet side of the pump, runs under the trap door in the floor and down the side of the ladder providing access to the flume. The "Tygon" tubing is connected to a piece of soft copper tubing, with 3/8-inch inside diameter, which is fastened to the ladder and extends down into the pool of water upstream of the Columbus weir. The inlet end of the copper tubing is about six feet upstream of the weir and two inches above the bottom of the concrete flume.

The Sears battery charger is connected to the Sentry Sampler and plugs into the receptacle box on the Warrick Floatless Control. The electrode fitting for the floatless control is supported on a ringstand

and two 5-foot brass electrodes extend down into the stilling well adjacent to the Columbus weir. The ringstand gives the adjustment required to keep the brass electrodes just above the water level in the stilling well so sampling can be started with initial storm-water runoff. The floatless control switch box is connected to the isolation transformer which connects to the 110-volt AC outlet available in the shelter.

Installation and Operation of Semi-Urban/Rural Watershed Sampling Equipment

The sampling equipment for the semi-urban/rural watershed is located in the concrete shelter just south of Kalberer Road, West Lafayette. The Sentry Sampler and other electrical equipment are located on a 2-foot by 3-foot shelf located 4½ feet above the shelter floor. The sampler stands on four 1½-foot wooden legs to allow room underneath for the sample containers. As with the urban sampling station, only 12 gallon containers are in place at one time. Samples are taken from the drainage ditch through a 30-foot length of soft copper tubing into the shelter. The copper tubing connects into a short piece of "Tygon" tubing on the inlet side of the pump.

The Sears battery charger is connected to the Sentry Sampler and plugs into the receptacle box on the Warrick Floatless Control. The electrode fitting and two 6-foot brass electrodes are supported above the stilling well by a ringstand place on the shelf. This arrangement allows for height adjustment when the base flow level in the drainage ditch changes. The floatless control switch box is connected to the isolation transformer which is connected to the 110-volt AC power outlet available in the shelter.

A galvanized "tee" was placed in the existing plumbing to facilitate the stilling well for the sampling equipment. A globe valve was installed between the tee and the polyethylene stilling well in case maintenance was required. Thus, the stilling well used for flow measurement does not need to be taken off-line when performing maintenance on the polyethylene well.

SAMPLING METHODOLOGY

Introduction

One of the main objectives of this study was to characterize the water quality of stormwater runoff from two watersheds, one urban and the other semi-urban/rural, located in West Lafayette, Indiana. The first decision in the sampling program was choosing the type of sample to be collected. The laboratory analyses to be performed on the samples were chosen next. After the laboratory analyses were decided on, the sampling interval and volume could then be determined. Lastly, the procedure for determination of sampling duration for each runoff event was chosen.

Type of Sample

It was decided that Sentry Sequential Composite Samplers previously purchased for another study would be used to collect stormwater runoff samples in this study. The Sentry Sampler permitted almost continuous sampling of runoff events by collecting individually composited samples which represented a subperiod within the overall sampling period. This continuous sampling, even during individual samples, was made possible by adjusting the length and number of pumping cycles.

One of the main reasons for choosing the sequential composite sampler was the ability to activate the sampler during initial runoff without the investigator being present. Initial sampling was important in order to obtain pertinent data in regard to "first flush" phenomenon. Without automation of the sampler, much data would have been lost due to the time required for the investigator to reach the sampling station.

Even disregarding the fact that the sampler could be activated during initial runoff, the sequential composited samples would generally be more consistent and reliable than grab samples. While it must be admitted that a composite sample may tend to dampen peak concentrations, these same peak concentrations may be missed even when using a grab sampling program. So it was concluded that sequential composited samples would best be used for the monitoring of the stormwater runoff events.

Laboratory Analyses

The analyses chosen were based on previous studies of stormwater runoff quality and the time available to run the analyses. The 5-day biochemical oxygen demand (BOD_5) and suspended solids tests were performed on all samples. Total and fecal coliforms were run on only some of the samples throughout the study period. All analyses were performed in accordance with the methods and procedures given in Standard Methods for the Examination of Water and Wastewater, Thirteenth Edition (39).

The BOD test was run with one initial and two final dissolved oxygen (DO) determinations. The DO determinations were made using the Winkler method. Normally, two or three dilution strengths were used. The suspended solids were determined using glass fiber filters. The multiple tube fermentation method of the coliform test was used in this study.

Sample Volume and Sampling Interval

The sample volume and the sampling interval are interrelated since enough pumping time must be allowed to obtain the desired sample volume. It was determined that approximately 1500 ml of sample would be required to perform the necessary analyses. Once the volume of sample was decided on, it was a matter of determining what sampling interval would be required to obtain this volume.

After some preliminary testing of the installed sampler, it was found that a half-hour sampling interval was sufficient to obtain 1500 ml of sample. The timing drum was programmed for two half-hour sampling periods per revolution. Each half-hour sampling period contained six 4-minute pumping cycles. The inlet line was not purged between aliquots or samples because this would have involved a loss of pumping time. It took about six minutes to purge and refill the inlet line. It was felt that obtaining a larger sample was more important than purging the line, especially since sampling was almost continuous.

Due to a slight variation in pumping time, it was necessary to place the pump cycle keys on the timing drum at five minute intervals to keep pumping cycles from over-lapping. If one pumping cycle overlapped the next, the second cycle would be lost because the microswitch would have been activated too early. Upon completion of the six 4-minute pumping cycles, the distribution arm was indexed to the next sample container.

The most important parameter, insofar as the impact of a pollutant on a receiving stream is concerned, is the pounds of that pollutant which must be assimilated by the stream. Therefore, it was logical that, in order to determine how frequent samples should be taken, it was first necessary to determine how the frequency of sampling effects the shape of the pollutograph (pounds of pollutant per unit time versus time throughout the storm event). For if there is, indeed, some maximum level of pounds of a pollutant that a stream can handle, then the concern should be with those values which exceed this level of discharge. For this reason, initial sampling methodology was concerned with peak emission rates and the effect of frequency of sampling on these peaks.

The data obtained during preliminary stormwater runoff events was formatted for the purpose of outlining the effects of the following conditions: 1) the effect of compositing one- and two-hour concentrations on the shape of the pollutograph using half-hour mean flows; 2) the effect of using one-hour and two-hour mean flow values, combined with the one- and two-hour mean sample concentrations on the shape of the pollutograph. A presentation of numerous Tables and Figures of the results of such an analysis is made in the partial report entitled "Stormwater Runoff Quality for Urban and Semi-Urban/

Rural Watersheds"(40). The general shape of the curves were not affected, except at peak values. The peak values decreased as the frequency decreased; i.e., the peak values decreased as the sampling interval increased. Table 1 shows the percent deviation from the original value for each situation. It can be seen that, generally, increasing the sampling interval increases the percent deviation as does increasing the mean flow interval used.

Sampling frequency significantly affects the shape of the quality graph. If an investigator is interested in "first flush" phenomena or the maximum values of concentration of a given pollutant, he must use a sampling frequency(interval) that will sufficiently describe these transient occurrences. There is no single sampling frequency that meets all possible circumstances because the frequency is dependent upon local conditions and the proposed use of the data.

As indicated earlier, because of the need to obtain a sufficient volume of sample, a sampling interval of 30 minutes was used throughout this study. When on occasion less than 1500 ml were collected, two successive samples were combined in order to obtain the desired volume of sample. This was particularly useful, and affected the results little, for the later stages of the runoff event when the concentration was low and/or relatively constant compared to the peak concentrations and/or flow in the early stages of the runoff.

Table 1

Percent Deviation in Peak Mass Emission Values Resulting From Various Sampling and Flow Intervals for Storms of Nov. 1 and Nov. 13, 1972 at the Two Test Watersheds

		Type of Composite								
		½ Hour Sample ½ Hour Flow	1 Hour Sample ½ Hour Flow		1 Hour Sample 1 Hour Flow		2 Hour Sample 1 Hour Flow		2 Hour Sample 1 Hour Flow	
Storm	Parameter	lb/day	lb/day	% Dev.	lb/day	% Dev.	lb/day	% Dev.	lb/day	% Dev.
Urban Station 11/1/72	SS	250	166	34	158	37	166	34	150	40
	BOD	39	35	12	28	28	33	17	26	34
Semi-Urban/ Rural Station 11/1/72	SS	5200	4450	14	4100	21	3250	37	3500	33
	BOD	397	397	0	382	4	394	1	385	4
Urban Station 11/13/72	SS	106	106	0	102	4	102	4	38	22
	BOD	32	32	0	30	8	32	1	26	18
Semi-Urban/ Rural Station 11/13/72	SS	13,800	12,800	7	13,000	6	12,500	9	12,600	9
	BOD	800	800	0	770	4	790	1	750	6

Sampling Duration

The duration of the sampling period for any runoff event was a matter of the investigator's discretion, unless the event was of short duration. Since the sampling stations accomodated only 12 sample containers, it was necessary to change them every six hours.

It has been shown that the mass emission rate of pollutants is highly dependent on volume of flow. The pounds of pollutants discharged were, in fact, directly related to the volume of flow; therefore, if it was desired to sample during 90 percent of the total mass emission it was necessary to sample for at least 90 percent of the runoff. Whether or not the sampling was continued beyond the first six hours, then, was based on subjective observations of the investigator.

The first of these subjective observations was made from the turbidity of the samples alreay collected. Turbidity was found to be a good characteristic upon which to base the "first flush" and subsequent quality of the stormwater runoff.

Other subjective observations which determined sampling duration were the rainfall intensity, stage recorders at the sampling station and weather conditions. The stage recorder was usually checked to see if the flow was on the ascending or descending side of the hydrograph as a help in deciding to continue sampling. The existing weather conditions offered some indication as to whether or not the main thrust of the storm was past.

PRESENTATION AND DISCUSSION OF DATA

Introduction

Stormwater runoff samples were collected from two watersheds (urban and semi-urban/rural) in West Lafayette, Indiana during the period October 1972 through May 1975. Most of the samples were collected during the summer and fall. A total of 26 and 18 individual storms were monitored at the urban and semi-urban/rural watersheds, respectively. The dates of these storms, along with a listing of the laboratory analyses performed on them, are presented in Table 2. Rainfall and flow data were not available for all storms monitored.

A brief discussion of the storms is presented in this section. Of particular interest is the matter of "first flush" phenomena, peak concentrations (mg/l), peak mass emission rates (lbs/day), and the effect of the antecedent dry period on them. Several examples of the flow hydrographs (flow rate versus time) and pollutographs (concentration versus time; and mass emission versus time) are given for each of the watersheds. Where permitted, a comparison of the runoff quality is made between the urban and the semi-urban/rural watershed.

For a more detailed discussion of the data, the reader is referred to other publications (40,41).

Table 2

Dates of Stormwater Runoff Events and Analyses Performed at the Urban and Semi-Urban/Rural Watersheds - (October 1972 through May 1975)

	Urban Watershed							Semi-Urban/Rural Watershed						
Date	Rain-fall	Flow	SS	VSS	BOD	TC	FC	Rain-fall	Flow	SS	VSS	BOD	TC	FC
10/27/72	0	X	X	0	X	X	X							
10/31/72	0	X	X	0	X	X	X							
11/1/72	0	X	X	0	X	X	X	0	X	X	0	X	X	X
11/7/72								0	X	X	0	X	0	0
11/10/72								0	X	X	0	X	0	0
11/13/72	0	X	X	0	X	0	0	0	X	X	0	X	0	0
7/20/73 A	0	X	X	X	X	X	0	0	0	X	X	X	X	0
7/20/73 P	0	X	X	X	X	X	0							
7/21/73	0	X	X	X	X	X	0							
8/11/73	0	X	X	X	X	X	X	0	0	X	X	X	X	X
8/13/73	0	X	X	X	X	X	X	0	0	X	X	X	X	X
8/14/73	0	X	X	X	X	X	X	0	0	X	X	X	X	X
9/14/73	0	X	X	X	X	X	X	0	0	X	X	X	X	X
6/21/74	X	X	X	0	X	0	0	0	0	X	0	X	0	0
7/19/74	X	X	X	0	X	0	0							
8/1-2/74	X	X	X	0	X	0	0	0	0	X	0	X	0	0
8/27/74 A	X	X	X	0	X	0	0							
8/27/74 P	X	X	X	0	X	0	0							
8/31/74	X	X	X	0	X	0	0							
9/11-12/74	X	X	X	0	X	0	0	0	0	X	0	X	0	0
10/23-24/74	X	X	X	0	X	0	0	0	0	X	0	X	0	0
11/3/74	X	X	X	0	X	0	0							
11/19-20/74	X	X	X	0	X	0	0	0	0	X	0	X	0	0
5/11/75	0	0	X	0	X	0	0							
5/19/75	0	0	X	0	X	0	0							
5/21-22/75	0	0	X	0	X	0	0	0	0	X	0	X	0	0
5/30/75 A	0	0	X	0	X	0	0	0	0	X	0	X	0	0
5/30/75 P	0	0	X	0	X	0	0	0	0	X	0	X	0	0

KEY: X = Data available.

0 = Data not available.

Quality of Dry Weather Flow

Grab samples were collected and analyzed during the study in order to determine the "baseline" quality level of the various parameters in the sewer (urban watershed) and the drainage ditch (semi-urban/rural watershed) before the start of rainfall and subsequent runoff. The data obtained from these grab samples are contained in Table 3.

As indicated, the "baseline" (dry weather) quality of the storm-water runoff was somewhat higher in the urban watershed than in the semi-urban/rural watershed. The average values of suspended solids (SS) and biochemical oxygen demand (BOD) were 27 and 15 mg/l and 37 and 2 mg/l at the urban and the semi-urban/rural watersheds, respectively. Maximum values of SS and BOD were 57 and 50 mg/l and 89 and 6 mg/l, respectively.

Baseline levels will generally not have any appreciable effect on the quality of initial runoff during larger storms. However, during very low flows the initial conditions in the sewer may have a more pronounced effect on the quality of runoff samples. During this condition, most of the pollutants found in the runoff may be from material in the sewer and not that washed from the watershed.

In addition to the data shown in Table 3 for the storm of August 9, 1973, the following results were obtained: PO_4-P = 0.3 mg/l and TKN = 1.1 mg/l at the urban watershed; PO_4-P = 0.4 mg/l and TKN = 1.5 mg/l at the semi-urban/rural watershed.

Table 3

Quality of Dry Weather Flow

Date	Urban Watershed				Semi-Urban/Rural Watershed			
	SS	BOD	Coliforms (per ml)		SS	BOD	Coliforms (per ml)	
	mg/1	mg/1	Total	Fecal	mg/1	mg/1	Total	Fecal
October 16, 1972	10	4			17	2		
July 11, 1973	39	9	3,320	230	89	2	0.7	0.11
July 19, 1973	45	12	750	46	66	2	23	2.1
July 26, 1973	30	7	460	93	60	2	24	1.1
August 9, 1973	21	10	460	93	53	5	15	0.4
June 20, 1974	11	4	-	-	12	2	-	-
July 3, 1974	3	3	-	-	12	2	-	--
July 25, 1974	26	14	-	-	32	2	-	-
August 1, 1974	26	50	-	-	58	5	-	-
August 7, 1974	38	27	-	-	33	2	-	-
August 22, 1974	6	8	-	-	26	6	-	-
August 26, 1974	5	12	-	-	18	4	-	-
September 9, 1974	52	22	-	-	24	2	-	-
September 11, 1974	57	30	-	-	12	2	-	-
Average*:	27	15	850	97	37	2	8.7	0.3
Maximum :	57	50	3,320	230	89	6	24	2.1

* Arithmetic mean; except for coliforms, which are geometric means.

Water Quality of Stormwater Runoff From The Urban Watershed

The data generated from samples of stormwater runoff of the urban watershed are tabulated in Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26. These data include suspended solids (SS), volatile suspended solids (VSS), biochemical oxygen demand (BOD), total coliforms (TC), and fecal coliforms (FC). Both concentration (mg/l) and mass emission (lb/day) values are given for the three former parameters. Total and fecal coliforms are given in MPN/ml. Where available, rainfall and flow data are presented.

Figures 9 and 10 are presented to show typical pollutographs for a stormwater runoff event at the urban watershed. The horizontal lines found in Figure 10 are half-hour averages for the specific parameter being presented. The curves are drawn to aid the graphic presentation and no specific values are implied by peaks and valleys contained in this figure or any of the others.

Figure 9 shows a pollutograph with the characteristic "first flush" phenomenon. This type of curve was obtained for approximately 80 % of the storm events at the urban watershed.

Figure 10 shows a two-stage type of flush. This storm consisted of two very intense half-hour cloudbursts spaced three hours apart. The "first flush" effect is present for both BOD and suspended solids. In addition, a "second flush", resulting from the second cloudburst, is evident for both BOD and suspended solids. In fact, the concentra-

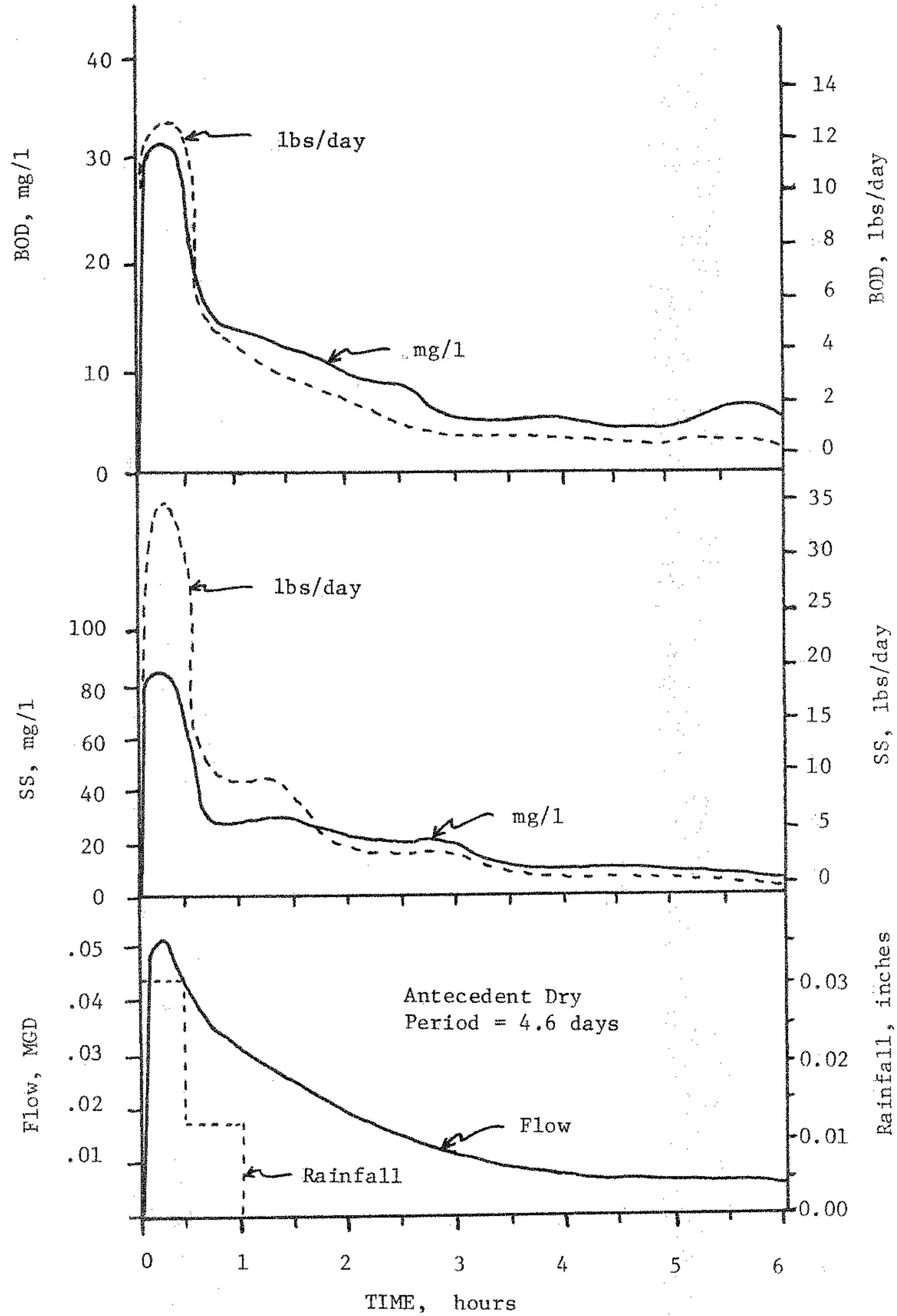

Figure 9 - Rainfall, Runoff, and Quality Data from Storm of October 27, 1972 at the Urban Watershed.

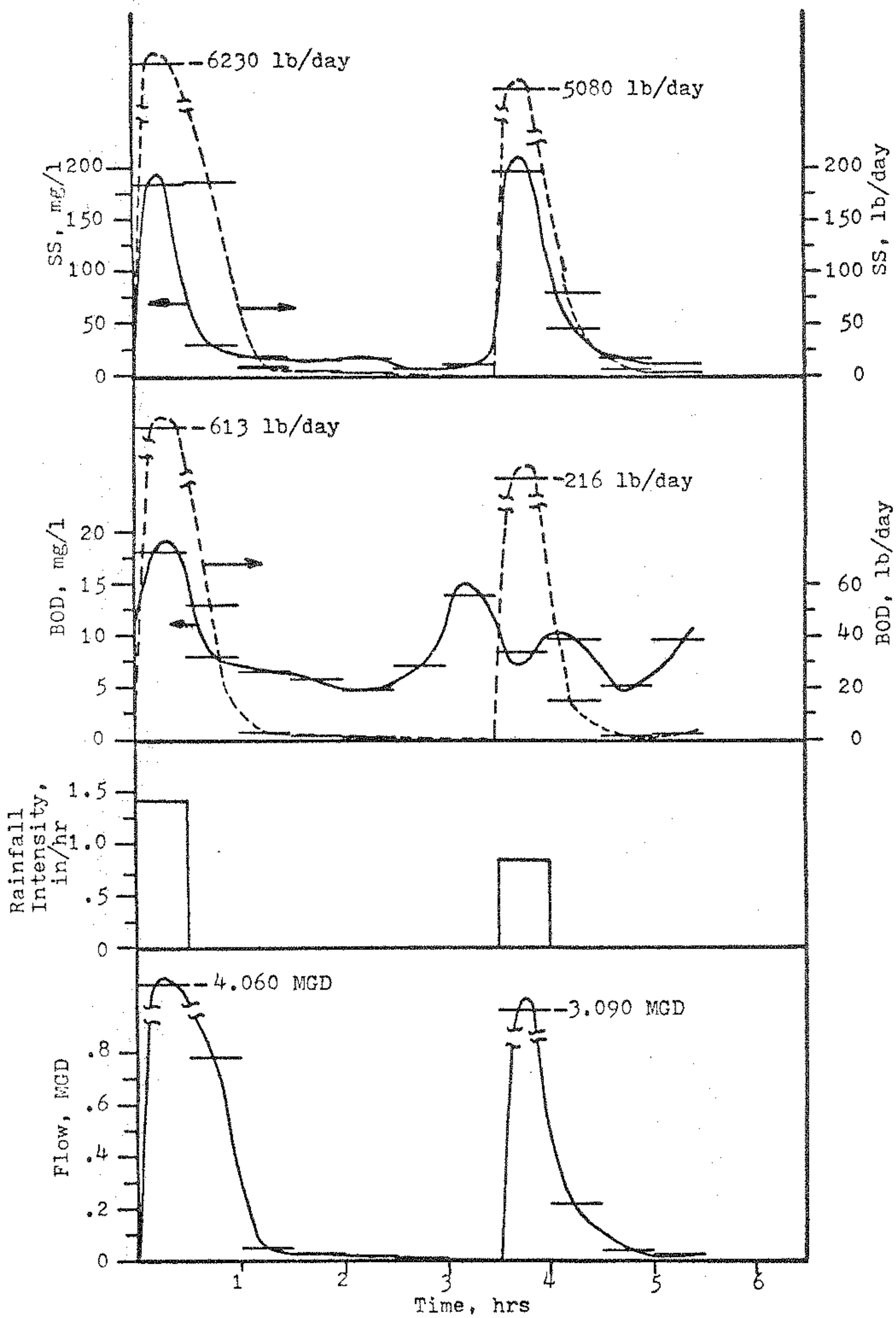

Figure 10 - Rainfall, Runoff and Quality Data from Storm of August 27, 1974 (PM) at Urban Watershed.

Table 4

Stormwater Runoff Data for the Urban Watershed

October 27, 1972

Time	Flow MGD	SS mg/l	BOD mg/l	SS lb/day	BOD lb/day	Coliforms: Total Organisms per ml	Coliforms: Fecal Organisms per ml
7:38 PM	.0460	83	30	31.8	11.4	15,000	930
8:08 PM	.0368	30	15	9.2	4.6	150,000	93,000
8:38 PM	.0308	34	12.6	8.7	3.2		
9:08 PM	.0247	20	10.8	4.1	2.2	24,000	24,000
9:38 PM	.0190	20	9.0	3.2	1.4	21,000	21,000
10:08 PM	.0141	28	4.0	3.3	0.5	93,000	43,000
10:38 PM	.0112	13	4.0	1.2	0.4		
11:08 PM	.0100	8	6.2	0.7	0.5		
11:38 PM	.0090	13	5.5	1.0	0.4	240,000	210,000
12:08 PM	.0080	9	4.7	0.6	0.3		
12:38 PM	.0075	6.5	6.0	0.4	0.4		
1:08 PM	.0070	6	7.0	0.4	0.4	7,500	7,500

Table 5

Stormwater Runoff Data for the Urban Watershed

October 31, 1972

Time	Flow MGD	SS mg/l	BOD mg/l	SS lb/day	BOD lb/day	Coliforms: Total Organisms per ml	Coliforms: Fecal Organisms per ml
9:42 AM	.0010	67	28	0.6	0.2	150,000	93,000
10:12 AM	.0013	31	34	0.3	0.4	930	430
10:42 AM	.0014	24	28	0.3	0.3		
11:12 AM	.0013	23	20	0.2	0.2		
11:42 AM	.0013	26	19	0.3	0.2		
12:12 PM	.0013	23	19	0.2	0.2	39,000	23,000
12:42 PM	.0014	15	19	0.2	0.2		
1:12 PM	.0047	40	19	1.6	0.7	24,000	24,000
1:42 PM	.0200	46	19	7.7	3.2		
2:12 PM	.0274	26	19	5.9	4.3		
2:42 PM	.0278	62	18	14.4	4.3		
3:12 PM	.0264	20	18	4.4	4.0		
3:42 PM	.0225	38	17	7.1	3.2	9,300	2,400
4:12 PM	.0222	11	19	2.0	3.5		
4:42 PM	.0212	9	>24	1.6	>4.2		
5:12 PM	.0190	12	>23	1.9	>3.6		
5:42 PM	.0180	16	>23	2.4	>3.4		
6:12 PM	.0180	16	>23	2.4	>3.4		
6:42 PM	.0170	12	>23	1.7	>3.2		
7:12 PM	.0111	20	>23	1.8	>2.1		
7:42 PM	.0051	36	>23	1.5	>1.0		
8:12 PM	.0040	32	>23	1.1	>0.8		
8:42 PM	.0042	28	>23	1.0	>0.8		

Table 6

Stormwater Runoff Data for the Urban Watershed

November 1, 1972

Time	Flow MGD	SS mg/1	BOD mg/1	SS lb/day	BOD lb/day	Coliforms: Total Organisms per ml	Coliforms: Fecal Organisms per ml
4:00 AM	.040	19	11	6.3	3.6		
4:30 AM	.105	16	10	14.0	8.8	93,000	43,000
5:00 AM	.157	13	9	17.0	11.5		
5:30 AM	.182	23	9	34.9	14.1		
6:00 AM	.168	32	10	44.8	13.8	24,000	9,300
6:30 AM	.145	21	9	25.4	11.0		
7:00 AM	.226	13	7	24.5	13.7	240,000	43,000
7:30 AM	.064	15	6	8.0	3.4		
8:00 AM	.050	26	6	10.8	2.6		
8:30 AM	.078	16	7	10.4	4.2		
9:00 AM	.154	12	6	14.8	8.3		
9:30 AM	.083	11	5	7.6	3.6		
10:00 AM	.045	10	5	3.8	1.7		
10:30 AM	.246	8	4	16.4	8.8		
11:00 AM	.554	8	4	34.6	20.5		
11:30 AM	.601	8	5	41.1	25.5		
12:00 PM	.337	16	6	44.9	16.5		
12:30 PM	.439	57	7	208.5	26.0		
1:00 PM	.504	54	8	226.8	33.9		
1:30 PM	.244	19	7	38.6	13.5	93,000	43,000
2:00 PM	.354						
2:30 PM	.283						
3:00 PM	.132						
3:30 PM	.079						

Table 7

Stormwater Runoff Data for the Urban Watershed
November 13, 1972

Time	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day	Coliforms: Total Organisms per ml	Coliforms: Fecal Organisms per ml
8:08 AM	.004	238	20	7.9	0.7		
8:38 AM	.012	114	35	11.4	3.5		
9:08 AM	.025	158	43	32.9	9.0		
9:38 AM	.037	60	32	18.5	9.8		
10:08 AM	.072	44	25	26.1	14.9		
10:38 AM	.132	65	23	71.5	25.7		
11:08 AM	.152	82	22	103.9	27.2		
11:38 AM	.087	52	20	37.7	14.5		
12:08 PM	.031	46	20	11.9	5.0		
12:38 PM	.011	38	28	3.5	2.6		
1:08 PM	.021	29	29	5.1	5.1		
1:38 PM	.033	22	23	6.1	6.4		
2:08 PM	.039	28	21	9.1	6.8		
2:38 PM	.043	28	22	10.0	7.7		
3:08 PM	.039	25	24	8.1	7.8		
3:38 PM	.059	27	24	13.3	12.0		
4:08 PM	.134	33	11	36.9	11.9		
4:38 PM	.132	34	8	37.4	9.2		
5:08 PM	.139	28	8	32.4	9.7		
5:38 PM	.271	24	8	54.2	19.0		
6:08 PM	.436	21	8	76.3	30.6		
6:38 PM	.331	31	8	85.5	23.3		
7:08 PM	.219	29	9	52.9	15.8		
7:38 PM	.279	27	9	62.8	20.6		
8:08 PM	.187	20	9	31.2	14.0		
8:38 PM	.121	17	9	17.1	9.2		
9:08 PM	.071	22	9	13.0	5.3		
9:38 PM	.046	24	9	9.2	3.4		
10:08 PM	.028						
10:38 PM	.019						

Table 8

Stormwater Runoff Data for the Urban Watershed

July 20, 1973

Time	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day	VSS mg/1	VSS 1b/day	Total Coliforms
4:30 AM	0.0029	65	5	2	0.1	40	1	1,500,000
5:00 AM	0.0020	50	5	1	0.1	39	1	24,000,000
5:30 AM	0.0019	41	6	1	0.1	28	1	
6:00 AM	1.115	143	12	1381	119	75	717	1,100,000
6:30 AM	2.122	40	13	108	226	20	354	930,000
7:00 AM	2.496	33	33	134	136	25	104	230,000
7:30 AM	1.844	80	81	1232	1252	39	592	2,400,000
8:00 AM	0.279	15	55	34	128	8	18	930,000
8:30 AM	1.433	70	12	825	138	24	279	2,400,000
9:00 AM	0.710	61	6	361	37	17	101	
9:30 AM	0.085	31	6	22	4	9	6	
10:00 AM	0.112	30	6	28	6	14	13	
10:30 AM	0.159	18	8	24	10	10	13	1,500,000
11:00 AM	0.095	22	8	17	6	16	12	
11:30 AM	0.024	--	8	--	2	--	--	430,000
12:00 PM	0.012	25	5	2	0.5	12	1	
12:30 PM	0.010	27	6	2	0.5	13	1	
1:00 PM	0.006							

Table 9

Stormwater Runoff Data for the Urban Watershed

July 20, 1973

Time	Flow MGD	SS mg/1	VSS mg/1	BOD mg/1	SS 1b/day	VSS 1b/day	BOD 1b/day	Total Coliforms per ml
5:00 PM	0.145	41	17	16	50	20	19	46,000
5:30 PM	0.095	53	26	14	42	20	12	
6:00 PM	1.134	99	35	28	742	333	269	
6:30 PM	1.947	63	16	38	1015	355	619	11,000
7:00 PM	0.097	66	26	19	53	21	16	
7:30 PM	0.036	39	15	17	12	5	6	
8:00 PM	0.016	46	15	10	6	2	1	930
8:30 PM	0.010	20	8	--	2	1	--	
9:00 PM	0.007	18	8	7	1	1	0.4	
9:30 PM	0.007	19	5	--	1	.2	--	2,300
10:00 PM	0.006	17	5	6	1	.2	0.3	
10:30 PM	0.004	11	4	--	1	.1	--	
11:00 PM	0.004	16	6	4	1	.2	0.1	750
11:30 PM	0.004	14	6	--	1	.2	--	

Table 10

Stormwater Runoff Data for the Urban Watershed

July 21, 1973

Time	Flow MGD	SS mg/l	VSS mg/l	BOD mg/l	SS lb/day	VSS lb/day	BOD lb/day	Total Coliforms per ml
12:00 AM	0.005	--	--	4	--	--	0.2	930
12:30 AM	0.156	9	6	5	11	8	5.8	
1:00 AM	0.775	30	15	4	194	97	27	
1:30 AM	0.128	40	8	4	43	9	3.8	2,300
2:00 AM	0.082	27	10	4	18	7	2.9	
2:30 AM	0.987	33	10	4	272	79	29	
3:00 AM	1.535	33	10	4	428	128	45	240
3:30 AM	2.307	42	12	3	808	226	62	
4:00 AM	0.821	30	8	4	205	53	26	
4:30 AM	0.415	18	5	3	61	19	11	430
5:00 AM	0.111							
5:30 AM	0.054							

Table 11

Stormwater Runoff Data for the Urban Watershed

August 11, 1973

Time	Flow MGD	SS mg/1	VSS mg/1	BOD mg/1	SS 1b/day	VSS 1b/day	BOD 1b/day	Coliforms(per ml) Total	Fecal
5:30 PM	2.497	87	18	8	1912	365	163	4,300	930
6:00 PM	0.176	63	16	8	92	23	12	2,700	230
6:30 PM	0.019	38	14	7	6	2	1	4,300	430
7:00 PM	0.004	28	11	6	1	.4	.2	4,300	930
7:30 PM	0.002	27	15	7	1	.2	.1	4,300	75
8:00 PM	0.001	23	12	5	.1	.1	.1	430	230
8:30 PM	0.054	46	15	7	20	7	3	930	75
9:00 PM	0.011	22	7	-	2	.6	-	2,300	430
9:30 PM	0.002	16	6	8	.2	.1	.1	4,300	230
10:00 PM	0.001	25	7	6	.1	.1	.04	2,300	930
10:30 PM	0.001	--	-	8	--	--	.03	750	43
11:00 PM	0.0004	24	11	6	.1	.1	.02	43	4

Table 12

Stormwater Runoff Data for the Urban Watershed

August 13, 1973

Time	Flow MGD	SS mg/1	VSS mg/1	BOD mg/1	SS 1b/day	VSS 1b/day	BOD 1b/day	Coliforms(per ml) Total	Fecal
11:15 PM	0.006	48	18	21	2	0.2	1	≥ 240,000	≥ 240,000
11:45 PM	0.025	28	10	13	6	2	3	≥ 240,000	≥ 240,000
12:15 AM	0.091	33	12	11	25	9	8	110,000	46,000
12:45 AM	0.434	43	14	6	155	49	21	2,400	460
1:15 AM	1.401	70	10	4	805	115	41	750	460
1:45 AM	0.261	27	6	6	58	13	12	24	9
2:15 AM	0.057	14	4	4	6	2	2	--	--
2:45 AM	0.014	15	7	4	2	0.8	.5	460	460
3:15 AM	0.004	36	12	3	1	0.4	.1	--	--
3:45 AM	0.015	26	11	4	3	1.3	.4	460	24
4:15 AM	0.032	--		5	-		1	--	--
4:45 AM	0.042	5		5	2		2	24	2

Table 13

Stormwater Runoff Data for the Urban Watershed

August 14, 1973

Time	Flow MGD	SS mg/1	VSS mg/1	BOD mg/1	SS 1b/day	VSS 1b/day	BOD 1b/day	Coliforms (per ml) Total	Fecal
11:30 AM	0.1561	43	21	19	55	27	24	-	-
12:00 PM	0.1074	33	14	14	30	13	13	-	-
12:30 PM	0.1273	42	17	14	44	18	15	-	-
1:00 PM	0.0304	20	8	8	5	2	2	430	75
1:30 PM	0.0215	16	6	7	3	1	1	1,100	150
2:00 PM	0.0166	13	6	6	2	1	1	460	21
2:30 PM	0.0064	13	5	5	1	.2	.3	150	75
3:00 PM	0.0034	15	4	6	.5	.1	.2	1,100	21
3:30 PM	0.0025	--	-	5	-	-	.1	93	23
4:00 PM	0.0018	15	8	4	.2	.1	.05	-	-
4:30 PM	0.0017	10	2	3	.1	.03	.05	150	21
5:00 PM	0.0016	14	7		.2	.09		-	-
5:30 PM				3				1,100	93
6:00 PM		20	7	4				-	-
6:30 PM		14	7	4				150	75

Table 14

Stormwater Runoff Data for the Urban Watershed

September 13 & 14, 1973

Time	Flow MGD	SS mg/l	VSS mg/l	BOD mg/l	SS lb/day	VSS lb/day	BOD lb/day	Coliforms (per ml) Total	Fecal
11:10 PM	0.1995								
11:40 PM	3.329	189	93	57	5,248	2,582	1,577	15,000	10,000
12:10 AM	1.363	95	44	36	1,072	495	412	-	-
12:40 AM	0.396	63	28	16	208	93	53	3,900	150
1:10 AM	0.422	31	19	9	109	68	32	430	93
1:40 AM	0.650	41	16	9	222	87	46	430	13
2:10 AM	0.793	27	14	7	179	89	49	4,300	93
2:40 AM	0.332	48	16	6	133	44	17	750	93
3:10 AM	0.134	--	16	7	---	18	8	4,300	93
3:40 AM	0.035	22	9	8	7	3	2	2,300	430
4:10 AM	0.015	53	26	10	6	3	1	750	150
4:40 AM	0.007	27	22	10	2	1	.6	1,500	43
5:10 AM	0.005	31	20	10	1	1	.4	2,300	230

Table 15

Stormwater Runoff Data for the Urban Watershed

June 21, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/1	BOD mg/1	SS lb/day	BOD lb/day
3:57 AM	0.09					
4:27 AM	0.07	0.026	27	13	6	3
4:57 AM	0.15	0.070	29	10	17	6
5:27 AM	0.11	0.282	19	7	45	16
5:57 AM	0.16	0.372	27	5	83	14
6:27 AM	0.17	0.532	35	4	153	18
6:57 AM	0.32	0.512	26	4	111	15
7:27 AM	0.11	0.760	47	3	299	22
7:57 AM	0.05	0.360	42	4	124	11
8:27 AM *	0.01	0.215	19	4	34	7

* Sampler malfunction at this time.

Table 16

Stormwater Runoff Data for the Urban Watershed

July 19, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/1	BOD mg/1	SS lb/day	BOD lb/day
3:44 AM	0.66	1.245	110	45	1140	467
4:14 AM	0.03	0.223	23	26	43	48
4:44 AM	0.13	0.081	18	24	12	16
5:14 AM	0.12	0.303	15	16	38	40
5:44 AM	0.01	0.120	5	15	5	15
6:14 AM	0.07	0.033	5	12	1	3
6:44 AM	0.02	0.078	3	12	2	8
7:14 AM	0.08	0.034	6	9	2	3
7:44 AM	0.13	0.236	6	9	11	18
8:14 AM	0.03	0.210	10	7	18	12
8:44 AM	0.03	0.035	9	7	3	2
9:14 AM *		0.015	11	8	1	1

* Complete sampling of runoff.

Table 17

Stormwater Runoff Data for the Urban Watershed

August 1-2, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/l	BOD mg/l	SS lb/day	BOD lb/day
10:25 PM	0.01					
10:55 PM		0.008	19	29	1	2
11:25 PM		0.005	24	26	1	1
11:55 PM *		-	--	--	-	-
12:25 AM	0.08	0.073	86	35	52	21
12:55 AM		0.025	47	29	10	6
1:25 AM **		0.008	6	20	0.4	1

* No flow

** Complete sampling of runoff.

Table 18

Stormwater Runoff Data for the Urban Watershed

August 27, 1974 (AM)

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day
9:57 AM	0.05	0.126	107	73	112	76
10:27 AM		0.032	34	66	9	18
10:57 AM *		0.015	25	63	5	13

* Complete sampling of runoff.

Table 19

Stormwater Runoff Data for the Urban Watershed

August 27, 1974 (PM)

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day
2:52 PM	1.42	4.060	184	18	6,230	613
3:22 PM		0.779	29	8	186	52
3:52 PM		0.051	19	7	8	3
4:22 PM		0.026	14	6	3	1
4:52 PM		0.017	15	5	2	1
5:22 PM		0.004	6	7	.2	.3
5:52 PM		0.002	10	14	.2	.2
6:22 PM	0.84	3.090	197	8	5,080	216
6:52 PM	0.01	0.216	44	10	79	18
7:22 PM		0.039	17	5	6	2
7:52 PM *		0.026	11	10	2	2

* Complete sampling of runoff.

Table 20

Stormwater Runoff Data for the Urban Watershed

August 31, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/l	BOD mg/l	SS lb/day	BOD lb/day
5:35 AM	0.02					
6:05 AM		0.085	92	34	65	24
6:35 AM		0.028	23	21	5	5
7:05 AM *		0.010	7	15	.6	1

* Complete sampling of runoff.

Table 21

Stormwater Runoff Data for the Urban Watershed

September 11-12, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/l	BOD mg/l	SS lb/day	BOD lb/day
4:35 PM	0.05					
5:05 PM	0.06	0.117	62	28	60	27
5:35 PM *	0.00	0.074				
6:05 PM	0.03	0.029				
6:35 PM	0.08	0.027				
7:05 PM **	0.02	0.078				
7:35 PM		0.169	39	11	54	15
8:05 PM		0.035	36	15	11	4
8:35 PM		0.030	28	9	7	2
9:05 PM		0.030	16	8	4	2
9:35 PM	1.29	2.481	127	29	2,630	598
10:05 PM	0.09	4.010	164	10	5,480	341
10:35 PM		0.200	61	5	101	9
11:05 PM		0.042	31	3	11	1
11:35 PM		0.031	17	4	4	1
12:05 AM	0.04	0.019	14	4	2	.6
12:35 AM		0.007	12	3	.7	.2
1:05 AM ***		0.004	12	4	.4	.1

* Sampler malfunction at this time.

** Sampling resumed.

*** Complete sampling of runoff.

Table 22

Stormwater Runoff Data for the Urban Watershed

October 23-24, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/l	BOD mg/l	SS lb/day	BOD lb/day
5:22 PM	0.04					
5:52 PM	0.02	0.080	254	195	169	130
6:22 PM	0.02	0.024	119	256	24	51
6:52 PM	0.02	0.014	81	275	9	32
7:22 PM	0.26	0.024	69	249	14	50
7:52 PM	0.04	0.651	200	109	1,090	592
8:22 PM	0.06	0.234	71	50	139	98
8:52 PM	0.04	0.052	52	52	23	23
9:22 PM	0.08	0.127	50	42	53	45
9:52 PM	0.00	0.244	39	35	79	71
10:22 PM	0.02	0.200	46	29	77	48
10:52 PM		0.054	29	30	13	14
11:22 PM		0.029	25	36	6	9
11:52 PM		0.020	19	31	3	5
12:22 AM		0.009	16	34	1	3
12:52 AM		0.004	17	33	.6	1
1:22 AM		0.002	16	34	.3	.5
1:52 AM *		0.002	15	33	.3	.5

* Complete sampling of runoff.

Table 23

Stormwater Runoff Data for the Urban Watershed

November 3, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/1	BOD mg/1	SS lb/day	BOD lb/day
6:28 AM	0.03					
6:58 AM	0.02					
7:28 AM	0.04					
7:58 AM	0.01	0.034	108	354	31	100
8:28 AM	0.19	0.433	110	417	397	1,510
8:58 AM	0.09	0.560	79	433	367	2,020
9:28 AM	0.00	0.189	63	334	99	526
9:58 AM	0.10	0.058	58	286	28	138
10:28 AM	0.02	0.222	40	139	74	257
10:58 AM	0.00	0.125	22	40	23	42
11:28 AM	0.01	0.059	11	31	5	15
11:58 AM	0.01	0.015	--	--	--	--
12:28 PM	0.51	1.826	28	214	419	3,260
12:58 PM	0.14	0.792	28	193	182	1,280
1:28 PM *	0.00	0.203	16	116	28	196
1:58 PM		0.071				

* Stopped sampling at this time.

Table 24

Stormwater Runoff Data for the Urban Watershed

November 19-20, 1974

Time	Rainfall Intensity (in/hr)	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day
10:59 PM	0.07	0.233	28	10	54	19
11:29 PM	0.02	0.121	76	8	77	8
11:59 PM		0.028	116	3	27	.7
12:29 AM		0.013	124	3	13	.3
12:59 AM *		0.006	90	2	5	.1

* Complete sampling of runoff.

Table 25

Stormwater Runoff Data for the Urban Watershed

May 11, 1975

Sample #	SS, mg/1	BOD, mg/1
1	433	106
2	38	38
3	15	30
4	9	26

May 19, 1975

Sample #	SS, mg/1	BOD, mg/1
1	192	172
2	55	91
3	15	53

May 21-22, 1975

Sample #	SS, mg/1	BOD, mg/1
1	388	78
10 *	307	9
11	212	7
12	69	7

May 30, 1975 (Morning)

Sample #	SS, mg/1	BOD, mg/1
1	1,660	34
2	135	9
3	81	10
4	73	6

* Sampler malfunction during samples 2-9.

Note: Rainfall & flow data not available.

Table 26

Stormwater Runoff Data for the Urban Watershed

May 30, 1975 (Afternoon)

Sample #	SS, mg/l	BOD, mg/l	Sample #	SS, mg/l	BOD, mg/l
1	148	12	7	370	6
2	280	6	8	249	5
3	124	4	9	91	6
4	191	5	10	83	3
5	128	5	11	82	4
6	215	21	12	55	4

Note: Rainfall & flow data not available.

tion of suspended solids was slightly higher during the "second flush" than during the "first flush".

The mass emission pollutographs were affected by both concentration and flow. However, as evidenced by Figures 9 and 10, and by Tables 4 through 24, the flow hydrographs had a much more significant effect on the shape and magnitude of the pollutograph than did the concentration.

Where coliform data were obtained, the results indicate that, in general, the fecal coliform count was approximately 30 percent of the total coliform count at the urban watershed.

Water Quality of Stormwater Runoff From The Semi-Urban/Rural Watershed

The data generated from samples of stormwater runoff of the semi-urban/rural watershed are tabulated in Tables 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, and 39. These data include suspended solids (SS), volatile suspended soilds (VSS), biochemical oxygen demand (BOD), total coliforms (TC), and fecal coliforms (FC). Both concentration (mg/l) and mass emission (lb/day) values are given for the three former parameters when available. Total and fecal coliforms are given in MPN/ml. Where available, flow data are

Table 27

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

November 1, 1972

Time	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day	Coliforms: Total Organisms per ml	Coliforms: Fecal Organisms per ml
3:15 AM	0.220	13	2.7	24			
3:45 AM	0.500	11	2.7	44	5	930	930
4:15 AM	1.130	14	2.8	135	11		
4:45 AM	1.210	23	2.9	232	26		
5:15 AM	0.820	31	3.2	211	29	9,300	9,300
5:45 AM	0.590	35	3.6	170	22		
6:15 AM	0.780	33	3.3	212	18	4,300	4,300
6:45 AM	1.380	34	2.7	385	21		
7:15 AM	2.310	33	2.7	639	32		
7:45 AM	2.650	33	3.6	718	52		
8:15 AM	2.820	32	4.0	740	79		
8:45 AM	2.620	30	4.0	655	94		
9:15 AM	2.240	27	4.0	508	87		
9:45 AM	1.930	24	4.0	378	74		
10:15 AM	2.220	21	4.0	379	64		
10:45 AM	2.570	20	4.1	433	75		
11:15 AM	2.000	24	4.1	397	87		
11:45 AM	3.320	30	4.2	830	68		
12:15 PM	6.720	30	4.3	1680	115		
12:45 PM	9.410	31	4.4	2430	240	46,000	4,300
1:15 PM	10.110	39	4.3	3290	346		
1:45 PM	10.770	53	4.2	4710	362		
2:15 PM	11.000	29	4.1	2660	372		
2:45 PM	10.300	19	4.0	1590	376		
3:15 PM	10.410				344		
4:15 PM	9.500						
5:15 PM	7.380						
6:15 PM	8.880						
7:15 PM	6.000						

Table 28

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

November 7, 1972

Time	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day
7:32 AM	.060	13	3.0	7	2
8:02 AM	.640	28	3.3	149	17
8:32 AM	.860	49	3.3	351	23
9:02 AM	.440	51	3.2	187	12
9:32 AM	.186	23	3.0	36	5
10:02 AM	.140	9	2.9	11	3
10:32 AM	.140	14	2.7	16	3
11:02 AM	.155	5	2.6	7	3
11:32 AM	.160	11	2.5	14	3
12:02 PM	.164	8	2.3	10	3

Table 29

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

November 10, 1972

Time	Flow MGD	SS mg/1	BOD mg/1	SS 1b/day	BOD 1b/day
4:42 PM	.0145	2.5	2.7	.30	.33
5:12 PM	.0443	2.4	2.6	.90	.95
5:42 PM	.0454	2.5	2.4	.95	.89
6:12 PM	.0382	5.5	2.2	1.75	.69
6:42 PM	.0280	2.5	2.0	.58	.47
7:12 PM	.0180	1.9	2.2	.29	.33
7:42 PM	.0120	1.7	2.5	.17	.25
8:12 PM	.0086	1.5	3.0	.11	.21

Table 30

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

November 13, 1972

Time	Flow MGD	SS mg/l	BOD mg/l	SS lb/day	BOD lb/day
10:12 AM	1.47	107	5.5	1,310	67
10:42 AM	3.10	164	5.8	4,237	150
11:12 AM	5.56	58	4.5	2,687	210
11:42 AM	7.80	137	5.1	8,905	330
12:12 PM	7.70	64	5.6	4,107	357
12:42 PM	6.45	81	6.1	4,354	329
1:12 PM	5.50	56	6.5	2,567	296
1:42 PM	4.93	65	6.3	2,683	259
2:12 PM	5.18	34	5.8	1,468	248
2:42 PM	5.80	51	5.4	2,465	259
3:12 PM	4.70	53	5.1	2,340	200
3:42 PM	4.50	54	4.8	2,250	180
4:12 PM	5.30	54	4.5	2,670	199
4:42 PM	7.40	54	4.3	3,690	265
5:12 PM	10.80	54	4.1	5,400	364
5:42 PM	15.18	58	3.8	7,337	484
6:12 PM	19.00	55	3.7	8,661	629
6:42 PM	20.40	73	4.0	12,324	675
7:12 PM	19.95	66	4.2	10,972	702
7:42 PM	19.88	76	4.5	12,591	751
8:12 PM	19.02	64	4.8	10,144	758
8:42 PM	17.31	57	5.1	8,222	730
9:12 PM	14.72	51	5.1	6,305	631
9:42 PM	11.70	46	4.9	4,486	476
10:42 PM	10.37				
11:42 PM	6.52				
12:42 AM	5.20				

Table 31

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

July 20, 1973

Time	SS mg/l	VSS mg/l	BOD mg/l	Total Coliforms per ml
5:00 AM	89	14	6	7.5
5:30 AM	100	14	8	---
6:00 AM	55	8	8	15
6:30 AM	108	9	5	---
7:00 AM	127	14	4	---
7:30 AM	76	10	5	21
8:00 AM	78	9	5	---
8:30 AM	70	7	5	110
9:00 AM	71	9	4	---
9:30 AM	69	11	3	---
10:00 AM	48	6	2	---
10:30 AM	43	7	4	4.3

Table 32

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

August 11, 1973

Time	SS mg/1	VSS mg/1	BOD mg/1	Coliforms (per ml) Total	Fecal
5:45 PM	233	28	10	--	--
6:15 PM	135	13	6	--	--
6:45 PM	146	20	4	15	< 3
7:15 PM	133	19	5	23	< 3
7:45 PM	262	42	7	43	4
8:15 PM	188	26	7	4	< 3
8:45 PM	261	21	4	75	9
9:15 PM	187	22	4	15	9
9:45 PM	---	--	4	--	--
10:15 PM	294	30	4	11	7
10:45 PM	283	25	4	23	23
11:15 PM	268	33	4	43	9

Table 33

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

August 13, 1973

Time	SS mg/l	VSS mg/l	BOD mg/l	Coliforms (per ml) Total	Fecal
11:15 PM	80	10	10	2.3	<.3
11:45 PM	65	11	5	2.3	.9
12:15 AM	80	11	5	.9	.9
12:45 AM	81	13	4	--	--
1:15 AM	83	14	4	--	--
1:45 AM	79	15	4	9.3	9.3
2:15 AM	62	5	5	--	--
2:45 AM	68	13	4	--	--
3:15 AM	74	11	4	9.3	9.3
3:45 AM	63	12	3	--	--
4:15 AM	49	11	4	--	--
4:45 AM	45	6	4	9.3	9.3

Table 34

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

August 14, 1973

Time	SS mg/1	VSS mg/1	BOD mg/1	Coliforms (per ml)	
				Total	Fecal
12:45 PM	--	--	2	.7	<.3
1:15 PM	26	8	2	--	--
1:45 PM	19	5	3	.4	<.3
2:15 PM	18	5	2	--	--
2:45 PM	15	5	2	.3	.3
3:15 PM	17	3	2	--	--
3:45 PM	18	4	2	2.3	2.3
4:15 PM	21	5	2	--	--
4:45 PM	23	3	2	.7	.4
5:15 PM	22	6	2	--	--
5:45 PM	22	5	2	1.5	1.5
6:15 PM	--	-	2	--	--

Table 35

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

September 14, 1973

Time	SS mg/l	VSS mg/l	BOD mg/l	Coliforms (per ml)	
				Total	Fecal
11:45 PM	46	13	5	9.3	.3
12:14 AM	72	11	7	43	.4
12:45 AM	52	9	5	21	7.5
1:15 AM	40	10	5	23	4.3
1:45 AM	48	8	4	23	4.3
2:15 AM	94	22	5	23	4.3
2:45 AM	66	14	5	23	4.3
3:15 AM	76	13	4	23	23.0
3:45 AM	61	8	4	23	9.3
4:15 AM	69	9	3	9.3	9.3
4:45 AM	64	15	4	23	9.3
5:15 AM	--	--	4	43	23.0

Table 36

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

June 21, 1974		
Sample #	SS, mg/l	BOD, mg/l
1	20	< 2
2	21	< 2
3	--	-
4	18	< 2
5	19	< 2
6	19	< 2
7	21	< 2
8	22	< 2
9 *	18	< 2

* Sampler malfunction at this time.

August 7, 1974		
Sample #	SS, mg/l	BOD, mg/l
1	46	6
2	23	7
3	17	7
4	16	7
5	19	6
6	13	7
7	17	7
8	16	7
9	16	7
10	14	7
11	14	6
12 **	15	7

** Stopped sampling at this time.

Table 37

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

September 11-12, 1974			September 27, 1974		
Sample #	SS, mg/1	BOD, mg/1	Sample #	SS, mg/1	BOD, mg/1
1	6	< 2	1	14	< 2
2	6	< 2	2	10	< 2
3	3	< 2	3	6	2
4	3	< 2	4	4	2
5	4	< 2	5	4	2
6	13	4	6	3	3
7	40	5	7	3	3
8	106	3	8	4	5
9	44	2	9	14	8
10	36	2	10	19	8
11	29	2	11	20	6
12	25	2	12	16	5
13	27	2	13	15	4
14	24	2	14	13	3
15 *	20	2	15	12	3
			16	9	2
			17	7	2
			18 **	7	< 2

* Stopped sampling at this time.

** Complete sampling of runoff.

Table 38

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

October 23-24, 1974			November 20, 1974		
Sample #	SS, mg/1	BOD, mg/1	Sample #	SS, mg/1	BOD, mg/1
1	20	< 2	1	38	< 2
2	19	< 2	2	58	4
3	22	2	3	64	7
4	25	6	4	85	7
5	23	6	5	88	7
6	27	7	6	97	-
7	25	7	7	116	7
8	27	7	8	118	6
9	19	6	9	124	5
10	30	6	10	92	5
11	20	5	11	90	4
12	21	5	12 **	88	4
13	18	5			
14	17	5			
15	17	4			
16	15	4			
17 *	15	4			

* Stopped sampling at this time.

** Stopped sampling at this time

Table 39

Stormwater Runoff Data for the Semi-Urban/Rural Watershed

May 21-22, 1975			May 30, 1975 (AM)			May 30, 1975 (PM)		
Sample #	SS, mg/1	BOD, mg/1	Sample #	SS, mg/1	BOD, mg/1	Sample #	SS, mg/1	BOD, mg/1
1	101	8	1	28	3	1	21	2
2	238	9	2	31	< 2	2	23	< 2
3	166	9	3	29	2	3	47	4
4	93	7	4	33	5	4	49	5
5	89	7	5	34	6	5	447	5
6	111	6	6	30	6	6	119	4
7	73	9	7	28	6	7	50	5
8	250	6	8	25	6	8	269	5
9	805	7	9	23	5	9	220	4
10	653	8	10	23	5	10	230	4
11	500	8	11	19	5	11	220	4
			12	20	4			

Note: Rainfall and flow data not available.

Figures 11 and 12 are presented to show typical pollutographs for a stormwater runoff event at the semi-urban/rural watershed. The horizontal lines found in Figure 12 are half-hour averages for the specific parameter being presented. The curves are drawn to aid the graphic presentation and no specific values are implied by peaks and valleys contained in this figure or any of the others. Figures 11 and 12, particularly Figure 11, show a pollutograph with the characteristic "first flush" phenomenon. As indicated, the first flush was primarily for the suspended solids and not for BOD. This was the case for most of the stormwater runoff events monitored at the semi-urban/rural watershed.

The mass emission pollutographs were affected by both concentration and flow. However, as evidenced by Figure 11 and Tables 27 through 30, the flow hydrograph had a much more significant affect on the shape and magnitude of the pollutograph than did concentration.

Where coliform data was obtained, the results indicate that, in general, the fecal coliform count was approximately 53 percent of the total coliform count at the semi-urban/rural watershed.

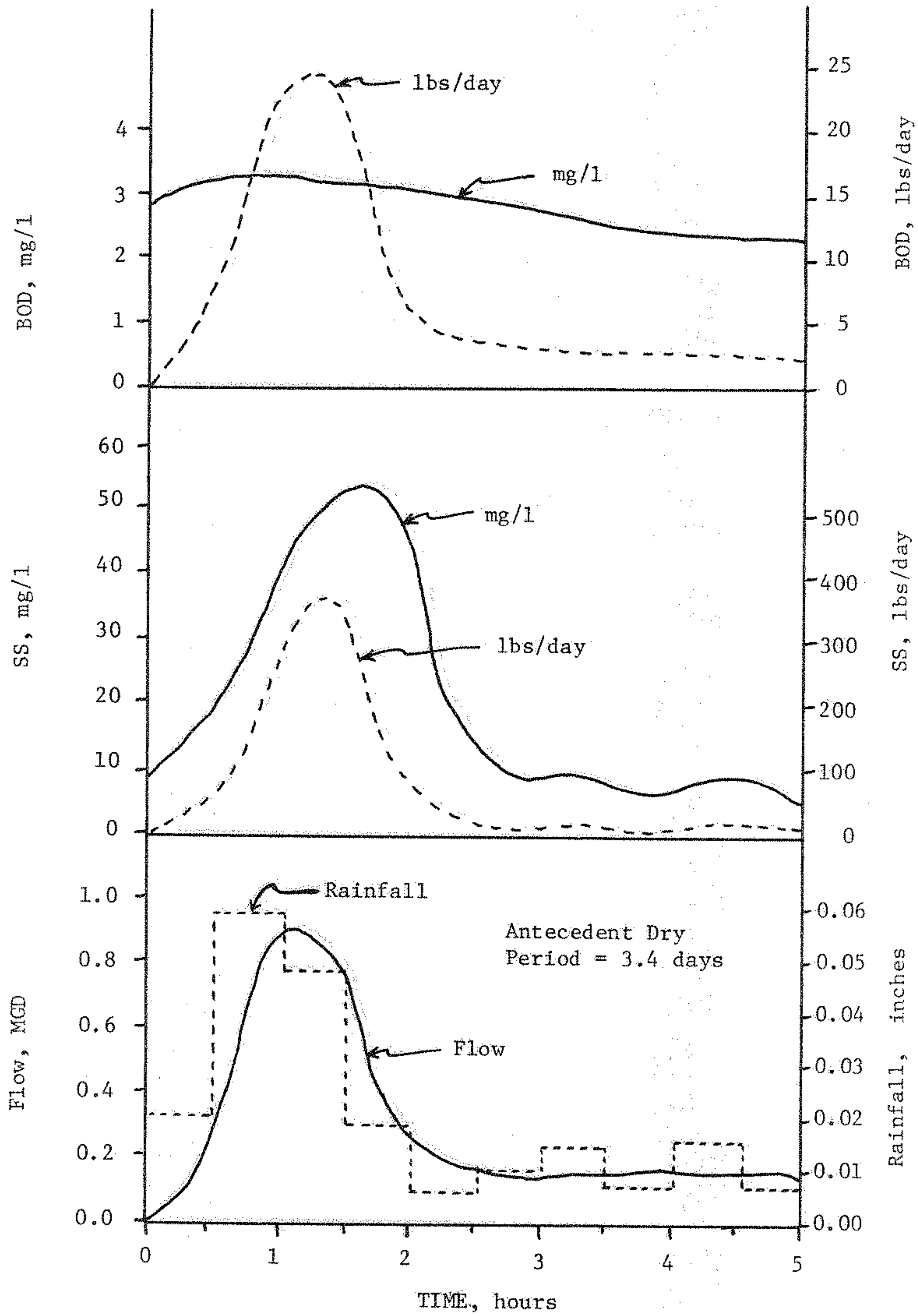

Figure 11 - Rainfall, Runoff, and Quality Data for Storm of November 7, 1972 at the Semi-Urban/Rural Watershed.

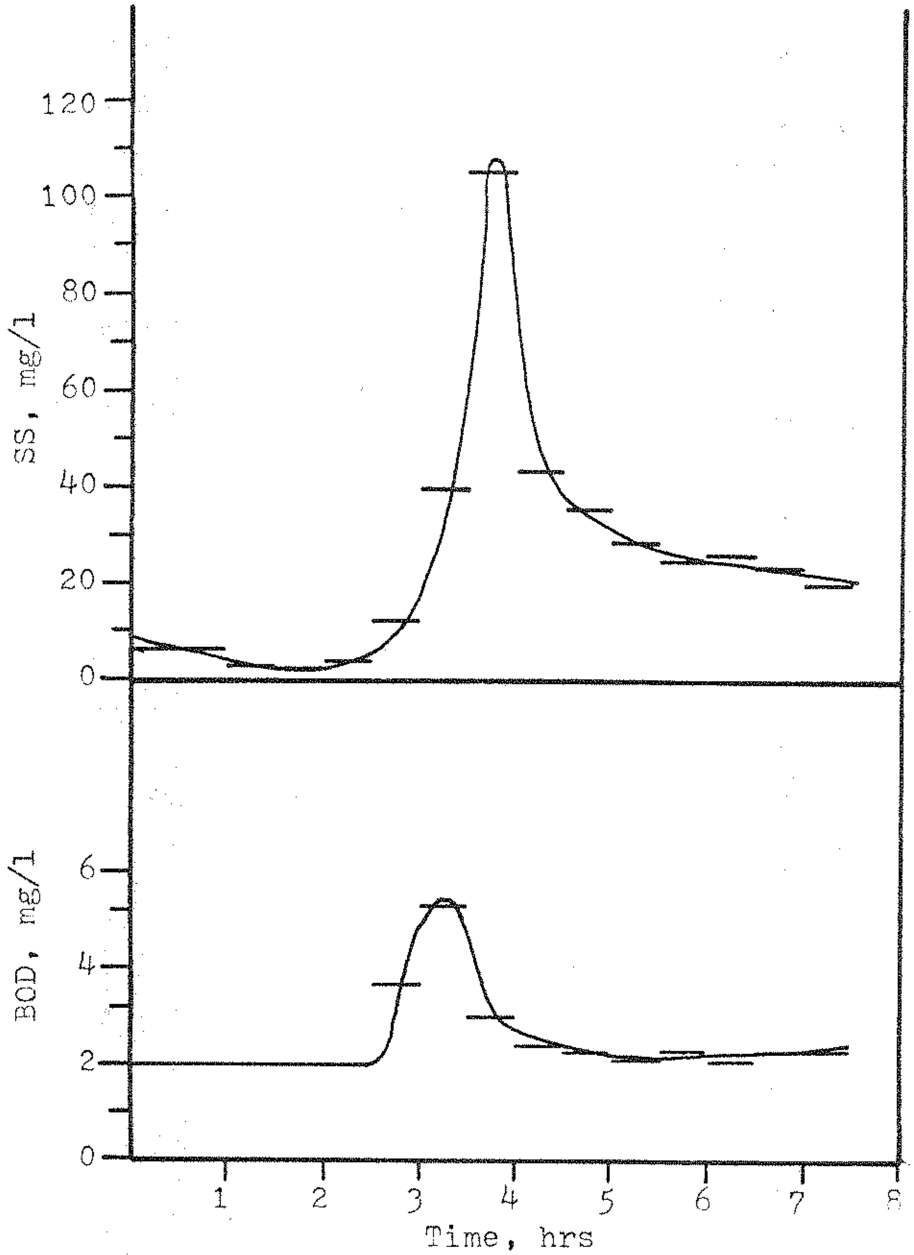

Figure 12 - Quality Data from Storm of September 11-12, 1974 at Semi-Urban/Rural Watershed.

Comparison of Runoff Quality at the Urban and Semi-Urban/Rural Watersheds

The range of BOD concentration varied significantly between the two watersheds. At the urban watershed, the maximum BOD concentration varied from a low of 5 mg/l to a high of 433 mg/l for all storms monitored (Table 40). The average BOD concentration ranged from 4 mg/l to 232 mg/l, with an overall average of 32 mg/l (Table 41). The range of maximum BOD concentration at the semi-urban/rural watershed was from less than 2 mg/l to 14 mg/l. The average BOD concentration ranged from less than 2 mg/l to 8 mg/l, with an overall average of 4 mg/l.

The suspended solids concentration also showed a significant variation between the two watersheds. The maximum suspended solids concentration at the urban watershed varied from a low of 42 mg/l to a high of 1,660 mg/l. The overall average was 76 mg/l with a range of 18 mg/l to 487 mg/l. At the semi-urban/rural watershed, the maximum suspended solids concentration varied from 6 mg/l to 805 mg/l. The average concentration varied from a low of 3 mg/l to a high of 280 mg/l, with an overall average of 70 mg/l.

The maximum BOD at the urban watershed is generally about 8-9 times higher than at the semi-urban rural watershed; based on those storms monitored at both watersheds. The urban watershed runoff generally has a maximum suspended solids concentration 1.5 to 2 times that of the semi-urban/rural watershed. Based on average concentrations, the urban watershed generally has about 4-5 times as much BOD

Table 40

Comparison of Maximum Concentrations at the Two Watersheds

Date	Urban Watershed SS	Urban Watershed BOD	Semi-Urban/Rural Watershed SS	Semi-Urban/Rural Watershed BOD
10/27/72	83	30		
10/31/72	67	34		
11/1/72	57	11	53	4
11/7/72			51	3
11/10/72			6	3
11/13/72	238	43	164	7
7/20/73 AM	143	81	127	14
7/20/73 PM	99	35		
7/21/73	42	5		
8/11/73	87	8	294	10
8/13/73	70	21	83	10
8/14/73	43	19	26	3
9/14/73	189	57	94	7
6/21/74	47	13	22	<2
7/19/74	110	45		
8/1-2/74	86	35	46	7
8/27/74 AM	107	73		
8/27/74 PM	197	18		
8/31/74	92	34		
9/11-12/74	164	29	106	5
10/23-24/74	254	275	30	7
11/3/74	110	433		
11/19-20/74	124	10	124	7
5/11/75	433	106		
5/19/75	192	172		
5/21-22/75	388	78	805	9
5/30/75 AM	1,660	34	34	6
5/30/75 PM	370	21	447	5

Table 41

Comparison of Average Concentrations at the Two Watersheds

Date	Urban Watershed SS	Urban Watershed BOD	Semi-Urban/Rural Watershed SS	Semi-Urban/Rural Watershed BOD
10/27/72	23	10		
10/31/72	28	23		
11/1/72	20	6	28	4
11/7/72			21	3
11/10/72			3	3
11/13/72	49	18	68	5
7/20/73 AM	47	16	78	5
7/20/73 PM	37	16	217	5
7/21/73	29	4		
8/11/73	36	7		
8/13/73	31	7	62	5
8/14/73	21	7	20	2
9/14/73	57	15	63	5
6/21/74	30	6	20	< 2
7/19/74	18	16	19	7
8/1-2/74	36	28		
8/27/74 AM	55	67		
8/27/74 PM	50	9		
8/31/74	41	24		
9/11-12/74	47	10	26	3
10/23-24/74	76	101	21	5
11/3/74	51	232		
11/19-20/74	87	5	88	5
5/11/75	124	50		
5/19/75	87	105		
5/21-22/75	244	25	280	8
5/30/75 AM	487	15	27	5
5/30/75 PM	168	7	154	4
Overall Average:	76	32	70	4

and 1-2 times as many suspended solids when based on those storms which were monitored for both watersheds. The overall average concentration shows the BOD is 8 times higher at the urban watershed. However, the suspended solids is only 1.1 times higher at the urban watershed.

In order to make some kind of reasonable comparison between the two watersheds, it was necessary to derive a useful factor which could reduce the pollutant values to a common basis. This was done by dividing the total pounds of pollutant washed from the watershed during a single storm event by the acreage of the watershed. Table 42 presents the pounds of pollutants per acre for the two watersheds. Because of the lack of flow data, only two storms (Nov. 11, 1972 and Nov. 13, 1972) can be compared. From the data in Table 42 it is evident that there is considerably more BOD and SS discharged at the semi-urban/rural watershed per acre than at the urban watershed.

For the storm runoff event of July 20 in which there was a storm in the morning as well as one in the evening, it can be noted that only about one-half the pollutant discharge (both BOD and SS) per acre was experienced during the second storm of the day.

In all cases, at the urban watershed, the amount of suspended solids discharged per acre was higher than the amount of BOD discharged per acre; except for the storm of 11/3/74.

In all cases, at the semi-urban/rural watershed, the amount of suspended solids discharged per acre was higher than the amount of BOD discharged per acre.

Table 42

Total Pounds of Pollutants Per Acre for the Urban and Semi-Urban/Rural Watershed

Date	SS, lbs/acre		BOD, lbs/acre	
	Urban	S-U/R	Urban	S-U/R
10/27/72	0.05		0.02	
10/31/72	0.04		0.04	
11/1/72	0.69	2.86	0.21	0.51
11/7/72		0.06		0.01
11/10/72		0.0004		0.0003
11/13/72	0.66	490	0.25	37
7/20/73 AM	3.4		1.5	
7/20/73 PM	1.4		0.7	
7/21/73	1.5		0.2	
8/11/73	1.4		0.1	
8/13/73	0.8		0.07	
8/14/73	0.1		0.04	
9/14/73	5.2		1.6	
6/21/74	0.7		0.1	
7/19/74	0.9		0.5	
8/1-2/74	0.05		0.02	
8/27/74 AM	0.1		0.08	
8/27/74 PM	8.2		0.7	
8/31/74	0.06		0.03	
9/11-12/74	6.0		0.7	
10/23-24/74	1.2		0.8	
11/3/74	1.2		6.7	
11/19-20/74	0.1		0.02	

Effects of Rainfall Intensity, Total Rainfall, and Antecedent Dry Period on Runoff Quality

Introduction

The possible effects and relationships of intensity, rainfall, and antecedent dry period on runoff quality are discussed in this section. However, this will only be done for the urban watershed, since rainfall and runoff data was not available for the semi-urban/ rural watershed.

A summary of the rainfall, intensity, and antecedent dry period is presented in Table 43.

Rainfall Intensity

Whether the storm was of short or long duration, the peak flow resulted from the period of maximum intensity. Maximum intensity may give an indication as to the degree of flushing produced by the storm. In other words, as the intensity of the rainfall increases, a more thorough cleaning of the watershed should occur. The data show an increasing trend of suspended solids concentration for all rainfall intensities above 0.3 in/hr. However, the storms with a maximum intensity of less than 0.1 in/hr also have a significant flush of suspended solids. The storm of Oct. 23-24, 1974 shows an extremely high suspended solids for a relatively low rainfall intensity. This can be explained by the fact that a very high "leaf drop" occurred just prior to this storm event.

Table 43

Summary of Rainfall Data for Storms

Sampled at Urban Watershed

Date	Total Rainfall (inches)	Maximum Intensity (in/hr)	Antecedent Dry Period (days)
June 21, 1974	0.62	0.32	0.2
July 19, 1974	0.65	0.66	22.2
Aug. 1-2, 1974	0.04	0.08	5.0
Aug. 27, 1974(AM)	0.02	0.05	4.6
Aug. 27, 1974(PM)	1.14	1.42	0.2
Aug. 31, 1974	0.01	0.02	3.4
Sept. 11-12, 1974	0.83	1.29	9.7
Oct. 23-24, 1974	0.30	0.26	9.1
Nov. 3, 1974	0.59	0.51	2.1
Nov. 19-20, 1974	0.04	0.07	3.2

Total Rainfall

It is logical to assume that an increased amount of rainfall should remove more of the pollutants from a given watershed. However, is it only the amount of rain or does the intensity affect the amount of pollutants washed off the watershed?

A plot of total pollutant washed from the watershed as a function of the total rainfall during that storm indicates that there is a relationship between the two. The reader is referred to another publication for more details of this relationship(41).

Antecedent Dry Period

Even though there was variation in the antecedent dry period between runoff events, no conclusions were reached in regard to its effect on runoff quality. In order to evaluate the effect of dry periods on runoff quality, it is also necessary to have the street cleaning schedule. Since street cleaning data were not available, attempts to analyze the effect of antecedent dry period were considered unadvisable.

Summary

The data clearly show a significant difference in the pollutional concentration of BOD and suspended solids between the urban watershed and the semi-urban/rural watershed. In all except a few cases, the peak concentration of pollutants was higher in the urban watershed; being about 1-2 times higher in suspended solids and 8-9 times higher in BOD. In average concentration, the suspended solids was about 1-2 times and the BOD 4-5 times higher in the urban watershed.

The mass emission pollutographs were affected by both concentration and flow. However, the flow hydrograph had a much more significant affect on the shape and magnitude of the pollutographs than did concentration.

A "first flush" of suspended solids and BOD was exhibited at the urban sampling station for most of the storm events. At the semi-urban/rural sampling station, very little "first flush" was observed for either BOD or suspended solids, although the latter exhibited such a phenomenon more than the former. During many of the storm events, peaks in suspended solids concentration occurred later in the storm, particularly in conjunction with sudden increases in flow. However, upon reaching the maximum flow for that storm, the concentration would then decrease and not rise again regardless of the flow pattern. This indicates that some "minimum" flow is required to completely flush the solids from the watershed and that, until such "minimum" flow occurs, various "peaks" in concentration can continue throughout the storm event due to sudden increases in flow.

Although the data would indicate that the antecedent dry period prior to a storm event has a definite effect on the magnitude of the mass emission pollutograph, not enough data were available to develop a reliable relationship between these two parameters. With additional data being obtained under Phase II of the project, efforts will be made to investigate this seemingly significant factor. At the same time, an investigation will be made concerning the frequency of street sweeping during such antecedent dry periods, particularly in the urban watershed.

CONCLUSIONS

1. The Sentry automatic sequential composite sampler used in this study was entirely adequate for obtaining samples of stormwater runoff.

2. The sampling frequency had a measureable effect on the peak value of the pollutograph. Decreasing the sampling frequency decreased the peak value by as much as 40 percent. The sampling frequency had little effect on the shape of the pollutographs except at peaks.

3. The sampling procedure, which consisted of collecting a 1-1.5 liter sample once every half-hour, was adeq ate for the purposes of this study.

4. The quality of the baseline (dry weather) flow and the conditions in a storm sewer at the start of a rainfall event has an effect on the quality of initial runoff, particularly during very low flows.

5. For a given stormwater runoff event, the pollutograph generally has a shape which is characteristic of the hydrograph. This indicates that flow is the most important contribution to the pollution loading from a stormwater runoff event.

6. In general, a "first flush" of BOD and suspended solids is observed at the urban watershed but not at the semi-urban/rural watershed.

7. The stormwater runoff from an urban watershed generally has a higher concentration of pollutants than from a semi-urban/rural watershed.

8. The peak BOD concentrations for the storms monitored at the urban and semi-urban/rural watersheds ranged from 5 to 433 mg/l and from 2 to 14 mg/l, respectively.

9. The peak suspended solids concentrations for the storms monitored at the urban and semi-urban/rural watersheds ranged from 42 to 1,660 mg/l and from 6 to 805 mg/l, respectively.

10. The total coliform counts for the runoff from the urban and semi-urban/rural watersheds ranged from 24 to 24,000,000 per ml and from 0.3 to 46,000 per ml, respectively.

11. The fecal coliform counts for the urban and semi-urban/rural watersheds ranged from 2 to 210,000 per ml and from 0.3 to 9,300 per ml, respectively.

12. Based on storms which were monitored at both watersheds, the maximum BOD concentration of the urban runoff will generally be about 8-9 times higher than the runoff at the semi-urban/rural watershed.

13. Based on storms which were monitored at both watersheds, the maximum suspended solids concentration of the runoff from the urban watershed will generally be about 1.5 to 2 times higher that the runoff from the semi-urban/rural watershed.

14. The urban runoff has an average concentration of BOD which is approximately 4-5 times higher than that of the semi-urban/rural watershed.

15. The urban runoff has an average concentration of suspended solids which is approximately 1.5-2 times higher than that of the semi-urban/rural watershed.

16. Based on the data obtained from stormwater runoff sampling during the summer, fall, and spring seasons, the water quality during the spring generally has a higher concentration of pollutants, especially in regard to suspended solids.

17. Maximum rainfall intensities, particularly above 0.3 in/hr, seem to have a direct relationship with the maximum suspended solids concentration; i.e., a higher maximum rainfall intensity will yield a higher maximum suspended solids concentration.

18. The data indicate that greater rainfall intensities will result in higher maximum BOD and suspended solids loadings.

19. The pounds of pollutants removed from the watershed appears to depend directly on the amount of rainfall.

BIBLIOGRAPHY

1. Burm, R.J., D.F. Krawczyk, and G.L. Harlow, "Chemical and Physical Comparison of Combined and Separate Sewer Discharges", Journal of Water Pollution Control Federation, Vol. 40, No. 1, Jan. 1968, p. 112.

2. Weidner, R.B., A.G. Christianson, S.R. Weibel, and G.G. Robeck, "Rural Runoff as a Factor in Stream Pollution", Journal of Water Pollution Control Federation, Vol. 41, No. 3, March, 1969, p. 377.

3. AVCO Economics Systems Corp., "Storm Water Pollution from Urban Land Activity", 11034FKL07/70, Federal Water Quality Administration, Dept. of the Interior, July, 1970.

4. Buckingham, P.L., C.S. Shih, J.G. Ryan, J.A. Lee, and J.K. Kane, "Combined Sewer Overflow Abatement Alternatives - Washington, D.C.", 11024EXF08/70, Roy F. Weston, Inc., Environmental Protection Agency, August, 1970.

5. Feuerstein, D.L., R.W. King, and A. Grimm, "Urban Storm Runoff and Combined Sewer Overflow Pollution - Sacramento, California", 11024FKM12/71, Envirogenics Company, Environmental Protection Agency, December 1971.

6. Angino, E.E., L.M. Magnuson, and G.F. Stewart, "Effects of Urbanization on Storm Water Quality: A Limited Experiment, Naismith Ditch, Lawrence, Kansas," Water Resources Research, Vol. 8, No. 1, February 1972, p. 135.

7. Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants", EPA-R2-72-081, URS Research Company, Enviromental Protection Agency, November 1972.

8. Hergert, S.L., "Urban Runoff Quality and Modeling Study", Masters Thesis, Dept. of Civil Engineering, University of Nenraska, Lincoln, Nebraska, December 1972.

9. Davis, P.L., and F.A. Borchardt, "Combined Sewer Overflow Abatement Plan", EPA-R2-73-170, Henningson, Durham, and Richardson, Inc., Environmental Protection Agency, April 1974.

10. Whipple, W., J.V. Hunter, and S.L. Yu, "Unrecorded Pollution from Urban Runoff", Journal of Water Pollution Control Federation, Vol. 46, No. 5, May 1974, p. 873.

11. Beers, G.D., "Management of Stormwater Runoff in Suburban Enviroments", Engineering Science, Inc., Office of Water Resources Research, U.S. Dept. of Interior, November 1973.

12. Schulz, J.W., "Pollutional Characteristics of Stormwater Runoff from Urban, Semi-Urban, and Rural Watersheds in West Lafayette, Indiana", Masters Thesis, Dept. of Civil Engineering, Purdue University, West Lafayette, Indiana, January 1969.

13. McElroy, F.T.R., III, "Development of Sampling Methodology for Monitoring Stormwater Runoff Quality for Urban and Semi-Urban/Rural Watersheds in the West Lafayette, Indiana Area", Masters Thesis, Dept. of Civil Engineering, Purdue University, West Lafayette, Indiana, May 1973.

14. Dornbush, J.N., J.R. Anderson, and L.L. Harms, "Quantification of Pollutants in Agricultural Runoff", EPA-660/2-74-005, South Dakota State University, Environmental Protection Agency, February 1974.

15. Burwell, R.E., G.E. Schuman, R.F. Diest, R.G. Spomer, and T.M. McCalla, "Quality of Water Discharged from Two Agricultural Watersheds in Southwestern Iowa", Water Resources Research, Vol. 10, No. 2, April 1974, p. 359.

16. Kluesener, J.W., and F.G. Lee, "Nutrient Loading from a Separate Storm Sewer in Madison, Wisconsin", Journal of Water Pollution Control Federation, Vol. 46, No. 5, May 1974, p. 920.

17. Thompson, G.B., D.M. Wells, R.M. Sweany, and B.J. Claborn, Interim Report, "Variation of Urban Runoff Quality and Quantity with Duration and Intensity of Storms - Phase III", Texas Tech University, Water Resources Center, Report No. WRC-74-2, August 1974.

18. Colston, N.V., Jr., "Characterization and Treatment of Urban Land Runoff", EPA-670/2-74-096, North Carolina State University, Environmental Protection Agency, December 1974.

19. Geldreich, E.E., "Fecal Coliform Concepts in Stream Pollution", Water and Sewage Works, Reference Index, 1967, pp. R98-R110.

20. Weibel, S.R., et al, "Characterization, Treatment, and Disposal of Urban Stormwater", International Conference on Water Pollution Research, 3rd, Munich, Germany, 1966, pp. 329-343.

21. Weibel, et al, "Pesticides and Other Contaminants in Rainfall and Runoff", Journal American Water Works Association, Vol. 58, No. 8, August 1966, pp. 1075-1084.

22. Weibel, S.R., et al, "Urban Land Runoff as a Factor in Stream Pollution", Journal Water Pollution Control Federation, Vol. 36, No. 7, July 1964, pp. 914-924.

23. Evans, F.L., III, et al, "Treatment of Urban Stormwater Runoff", Journal Water Pollution Control Federation, Vol. 40, No. 5, May 1968, pp. R10-R170.

24. Palmer, C.L., "Feasibility of Combined Sewer Systems", Journal Water Pollution Control Federation, Vol. 35, No. 2, February 1963, pp. 162-167.

25. Palmer, C.L., "The Pollutional Effects of Stormwater Overflows from Combined Sewers", Sewage and Industrial Wastes, Vol. 22, No. 2, February 1950, pp. 154-155.

26. Burm, R.J., and Vaughn, R.D., "Bacteriological Comparison Between Combined and Seaparate Discharges in Southeastern Michigan", Journal Water Pollution Control Federation, Vol. 38, No. 3, March 1966, pp. 400-409.

27. Benzie, W.J., and R.J. Courchaine, "Discharges from Separate Storm Sewers and Combined Sewers", Journal Water Pollution Control Federation, Vol. 38, No. 3, March 1966, pp. 410-421.

28. Geldreich, E.E., et al, "The Bacteriological Aspects of Stormwater Pollution", Journal Water Pollution Control Federation, Vol. 40, No. 11, November 1968, pp. 1861-1872.

29. Public Health Service, "Pollutional Effects of Stormwater and Overflows from Combined Sewer Systems - A Preliminary Appraisal", U.S. Dept. of Health, Education, and Welfare, U.S. Public Health Service, Division of Water Supply and Pollution Control, November 1964.

30. Bryan, E.H., "Quality of Stormwater Drainage from Urban Land Areas in North Carolina", Office of Water Resources Research, Dept. of the Interior, June 1970.

31. "Interpretations of Data Collected During Stormwater Sampling Programs", Los Angeles County Flood Control District, Water Conservation Division, Memorandum, File No. 2-19.02, August 13, 1963.

32. "Interpretation of Data Collected During 1964-68 Seasons", Los Angeles County Flood Control District, Lettergram, File No. 2-19.02, August 16, 1968.

33. Waller, D.H., "Selected Information About Reported Research on the Subject of Pollution Due to Stormwater and Overflows from Combined Sewage", Atlantic Industrial Research Institute, Technical Report No. 1, Central Mortgage and Housing Corporation Project on Pollution Due to Stormwater and Overflows From Combined Sewers, Nova Scotia Technical College, Halifax, Nova Scotia.

34. Vilaret, M.R., and R.D.G. Pyne, "Storm and Combined Sewer Pollution Sources and Abatement - Atlanta, Georgia", 11024ELB01/71, Black, Crow & Eidness, Inc., Environmental Protection Agency, January 1971.

35. "Stream Pollution and Abatement from Combined Sewers - Bucyrus, Ohio", Section 7, Combined Sewer Overflow Abatement Technology, 11024-06/70, Federal Water Quality Administration, Dept. of the Interior, June 1970.

36. Vicran, E.B., and J.W. Delleur, "Hydrologic Study of an Urban Watershed in West Lafayette, Indiana", Tech. Report No. 12, Hydromechanics Laboratory, Purdue University, February 1966.

37. Sarma, P.B.S., "Effects of Urbanization on Runoff from Small Watersheds", Ph.D. Thesis, Dept. of Civil Engineering, Purdue University, January 1970.

38. Golenberg, M., "An Evaluation of Methods for Up-Dating Origin and Destination Studies", Masters Thesis, School of Civil Engineering, Purdue University, June 1966.

39. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 13th Edition, New York, N.Y., 1971.

40. McElroy, F.T.R., III, and J.M. Bell, "Stormwater Runoff Quality for Urban and Semi-Urban/Rural Watersheds", Technical Report No. 43, Water Resources Research Center, Purdue University, West Lafayette, Indiana, February 1974.

41. Hartman, D.W., "The Monitoring and Prediction of Stormwater Runoff Quality From Watersheds in West Lafayette, Indiana", M.S.C.E. Thesis, School of Civil Engineering, Purdue University, December 1975.